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The colourful sea cucumber or sea apple, *Pseudocolochirus violaceus*, found at Cemetery Reef during survey work. Photo: Lisa Kirkendale.

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AUSTRALIA'S DIGGING MAMMALS AS ECOSYSTEM ENGINEERS: IMPLICATIONS FOR CONSERVATION AND ECOSYSTEM RESTORATION

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ABSTRACT

Australia's digging mammals represent allogenic ecosystem engineers and are keystone species. Their bioturbation activities create, destroy, maintain, or modify their abiotic environment, which feeds-back upon the biota and has profound effects influencing ecosystem health. The beneficial role of Australian digging mammals, many now threatened with extinction, highlights the imperative of conserving these species. Over the past two centuries Australia has suffered widespread declines and extirpations of native digging mammals. Loss of ecosystem engineering by native ecosystem engineering species appears to have contributed to environmental degradation. Further demises of native ecosystem engineering species, and the ecosystem functions they perform through their direct impacts upon their abiotic environment, is a major conservation concern, with far-reaching, cascading consequences for Australia's environments and the biota they contain. Digging native mammals therefore represent focal species to direct conservation efforts towards. Through reintroductions to restore such species to their former range and abundance, their ecosystem engineering activities can facilitate restoration of Australia's degraded landscapes and enhance ecosystem diversity. Although not perfect analogues, introduced bioturbators – namely rabbits – are also ecosystem engineers. Whilst at high densities rabbits can cause environmental degradation, their wholesale extermination can have unintended detrimental consequences. It is important that Australia's ecosystem engineering digging mammals be focal components in theoretical and applied ecological studies and projects involved in species conservation and ecosystem restoration.

INTRODUCING AUSTRALIA'S DIGGING MAMMALS AS ECOSYSTEM ENGINEERS

Many of Australia's mammalian fauna engage in digging activity, involving excavations from nose-digs, shallow scrapes, and foraging pits constructed whilst foraging for underground insects, roots, seeds or tubers, or by constructing larger, durable dens and burrows for shelter or rearing young (Table 1). Such digging mammals exemplify ecosystem engineers. An ecosystem engineer is "an organism that modifies, creates or destroys habitat and directly or indirectly modulates the availability of resources to other species, causing physical state changes in biotic or abiotic materials." (Bledzki 2010) Via their bioturbation activity, Australian digging mammals assume the role of allogenic eco-engineers: ecosystem engineering species that "change the environment by transforming living or non-living materials from one physical state to another, via mechanical or other means." (Bledzki 2010).

Through their digging activities, mammalian bioturbators influence and enhance a range of abiotic and biotic ecosystem properties across a diversity of spatial and temporal scales, contributing to ecosystem health, productivity and biodiversity (Table 2, Fig. 1). Critical roles digging mammals assume in edaphic processes and habitat dynamics may have effects extending across a range of spatial and temporal scales, including those of evolutionary significance. The structurally mediated modification of their abiotic environment by digging mammals in turn influences biota – both the engineer and sympatric species – at the level of the individual organism to entire ecosystems, with profound ecological and evolutionary outcomes (Prendergast 2012). Effects of digging activities performed whilst excavating underground dietary items or constructing underground shelters include (Table 2, Fig. 1):

- Altered physical soil properties
- Providing an important geomorphic mechanism for mobilizing substantial volumes of soil, contributing to soil turnover rates and erosional processes
- Contributing to pedogenesis and improve soil formation rates
- Effecting the inoculation of mycorrhizal spores important for plant growth in many Australian ecosystems
- Improving seed dispersal and germination
- Affecting litter build-up, which influences fire dynamics
- Influencing patch dynamics
- Affecting nutrient cycling and contribute to soil and nutrient stores
- Maintaining and supporting a diversity of niches for microbial, fungal, animal and plant biota

- Providing refuges for biota
- Affecting soil compaction, water-repellency, and water infiltration.

Investigations have demonstrated how mammal bioturbators have major effects on ecosystem processes such as soil turnover and associated mixing of organic matter, and promoting soil biota growth, both critical for soil productivity. Their excavations entrap organic material and seeds, acting as fertile, nutrient-rich fermentation sites for seeds (see Fey *et al.* 2010, Garkaklis 2001, Garkaklis *et al.* 1998, James 2004, James *et al.* 2009, James and Eldridge 2007, Newell 2009, Valentine *et al.* 2011, Whitford and Kay 1999). If the species seed-caches (exemplified by the seed-caching behaviour of Brush-tailed bettongs *Bettongia ogilbyi* important for sandalwood *Santalum spicatum* recruitment) this further contributes to seed dispersal and germination (Murphy *et al.* 2005).

Ecosystem engineering can be expected to be important in enhancing biodiversity within a landscape by increasing habitat complexity and heterogeneity; facilitating occupation of otherwise intolerable abiotic conditions for biota; influencing metapopulation dynamics with the associated population genetic and demographic consequences; and markedly promoting the potential for niche differentiation, diversification and co-existence between species both within and between trophic levels (Laland *et al.* 1999, Mullan Crain and Bertness 2006, Odling-Smee *et al.* 2003, Wright and Jones 2004, Wright and Jones 2006). Australia's digging mammals play a key role in critical ecosystem processes, functioning and biodiversity, with impacts occurring over a range from micro to macro spatial and temporal scales. Ecosystem engineering mammals are vital components of ecosystems (Jones *et al.* 1994, Jones *et al.* 1997). Representing keystone species, Australia's ecosystem engineering mammals play an important role in promoting overall biodiversity at all levels (including genetic diversity, species richness and diversity within communities, and at the level of ecosystems).

Harsh, resource-limited dryland ecosystems cover 70% of Australia's 7.5 million km^2 landmass (Byrne *et al.* 2008). Ecological theory predicts ecosystem engineering effects, especially on plant species richness, are most potent in resource-limited environments typifying much of the Australian landscape. Because species are at the extremes of their physiological tolerances, moderation/amelioration of abiotic extremes/stresses and small increases in resource availability in these water and nutrient limited systems engendered by ecosystem engineers' digging activity and their resultant structures are expected to have disproportionate effects (Wright and Jones 2004, Huang 2007). In arid systems, altering

Table 1. Illustrative examples of digging mammal taxa and their eco-engineering activities.

Species	IUCN conservation status*	Distribution	Biological characteristics	Eco-Engineering activities and Bioturbation characteristics	References
Echidna, *Tachyglossus aculeatus*	LC	Widespread.	Medium-sized monotreme. Myrmecophagous. Solitary forager.	Produce range of bioturbation disturbances - nose pokes, shallow to deep digs, extensive tracts of bulldozing – over extensive areas. Foraging pits are created when foraging for ants, termites and grubs, creating a mosaic of foraging pits close to canopies of trees. Construct resting sites. Construct nursery dens ~1m long, typically dug at the base of a termite mound or between tree roots, in which the highly altricial young (puggle) is left after it leaves the female's pouch.	Eldridge and Mesinga 2007; Jones and Parish 2006
Greater Bilby, *Macrotis lagotis*	VU	Historically widespread; now restricted to fragmented populations in the WA/NT border, and SW QLD.	Medium-sized semi-fossorial peramelid marsupial. Omnivorous. Solitary or lives in small family groups.	Constructs foraging pits when foraging for insects, bulbs and fungi. Digs residential burrows for shelter; each individual maintains up to 12 burrows, 3m long, with a single entrance, which spiral down. Dug at the base of termite mounds, shrubs or grass.	James 2004; James and Eldridge 2007; Read *et al.* 2008; Jones and Parish 2006
Bandicoots (*Perameles* sp., *Isoodon* sp.)	Varies with species e.g. *Isoodon obesulus fusciventes*, LC, *Perameles gunni*,	Continent-wide family distribution, at the species level, many geographically restricted and have undergone	Small fossorial peramelids. Omnivorous. Can occur at high densities.	Constructs characteristic conical pits 2-4 cm wide and 3-5 cm deep with their strong fore-claws, using their elongated snout as a probe, whilst foraging for invertebrates (earthworms, adult and larval), hypogeal fungi,	Braithwaite 1995; Martin 2003

	EN	range contractions since European colonization.		and subterranean plant material. Construct nesting depressions by scraping away to create shallow depressions overlain with a heap of ground litter, producing an internal chamber with loose regions either end for entry/exit, often concealed within shrubs, piles of debris or logs.	
Brush-tailed bettong, *Bettongia pencillata*	CR	Once widespread yet following European colonization range has contracted by 97%; only 3 relict populations remain in SW WA.	Medium-sized semi-fossorial potoroid marsupial. Feeds extensively on underground fruiting bodies of fungi.	Digs many small ellipsoid foraging pits, constructed by digging down, to locate subterranean fungi (e.g. truffles), concentrated within 2m of trees hosting mycorrhizae. Their activities disperse fungal spores, promotes plant growth via inoculating plants with mycorrhizal fungi. The disperse seeds and promote germination by seed-caching. Pits have a steep wall to a depth of 10-15cm, with a shallow wall and spoil heap formed as material is ejected to the rear. Produce 5,000-16,000 diggings/ha/y in schlerophyll woodland, yet av. digging rate of 22,000 diggings/woylie/yr (=47 digs/woylie/night) was recorded for introduced woylies in Whiteman Park, Swan Coastal Plain. Diggings enhance fungal growth, activity and density within pits. Construct nests that are resided in during the day; nests are constructed as shallow scrapes at the base of *Xanthorrhoea* bushes built from sticks and leaves brought to the bush carried with their tail.	Christensen 1980; Garkaklis *et al.* 1998, 2000, 2003, 2004; Umbrello 2010

Table 1. (cont.)

Species	IUCN conservation status*	Distribution	Biological characteristics	Eco-Engineering activities and Bioturbation characteristics	References
Burrowing bettong, *Bettongia lesueur*	VU	Prior to European colonization had the largest distribution of all native mammals of Australia. By 100ya became extinct from the mainland. Currently occupies <1/10,000 of its former range; survives only on islands off the WA coast, or recently in predator-proof fenced enclosures from re-introduction projects.	Similar to *B. pencillata* Once may have occurred at population densities of 35 bettongs/ km^2.	Excavates permanent and highly distinctive subcircular warrens, typically 17.5m, but up to 30m in diameter. Warrens are characterized by a perimeter mound surrounded by large stones kicked out by the animal's powerful hindlegs whilst burrowing. Within the perimeter is located a distinct central lens of calcrete below which bettongs tunnel-out galleries, however little investigation has been made into the dimensions and design of these subterranean galleries.	Noble *et al.* 2007
Southern hairy-nosed wombat (*Lasiorhinus krefftii*)	LC	Historically widespread, however range has now become restricted to small isolated populations in South Australia.	Of the three wombat spp., the southern hairy-nosed wombat occurs in the most arid environments, and is the most arid-adapted. Wombats are one of the largest of marsupials.	Dig open burrow systems occupied during the entire lifespan of an individual and over successive generations. Often construct a central warren with small simple perimeter burrows. Most burrows have 1-2 entrances and are 4-28m long, but large complex warrens can have 28 entrances and a total length of 89m on several levels. Include several nesting chambers lined with vegetation. Depth of tunnels is 1m in firm soil and 4m in sandy	Johnson 1990; Tyndale-Biscoe 2005; Loffler and Margules 1980.

			Occurs in small groups.	soil. Volume of warrens are between 8-13m^3. Rapid excavators: one subadult wombat can dig a tunnel 4m long in 30min. Burrow systems occupy an area of 314-706.5cm^2, Massive sediment displacement (214.5 - 918.5 m^3 of soil is displaced). Mounds created by tailings rise 1m above surrounding topography. Area of activity is at densities of 0.1-0.3/ ha. Structures produced from bioturbation have a persistence time of >50yrs.	
European rabbit, *Oryctolagus cuniculus* (introduced)	LC	Widespread and abundant.	Medium-sized fossorial lagomorph. Grazing herbivore. Lives in communal underground warrens but grazes on the surface. Occurs at high densities.	Constructs large, subterranean complex burrow systems (warrens); construction is ongoing. Foraging activity occurs at <20cm spatial scales, producing shallow diggings creating a mosaic of small pits interspersed with patches of cryptogram crust and subsoil microdeposit mounds.	Kolb 1991; Eldridge and Myers 1999, 2000, 2001; Eldridge *et al.* 2006

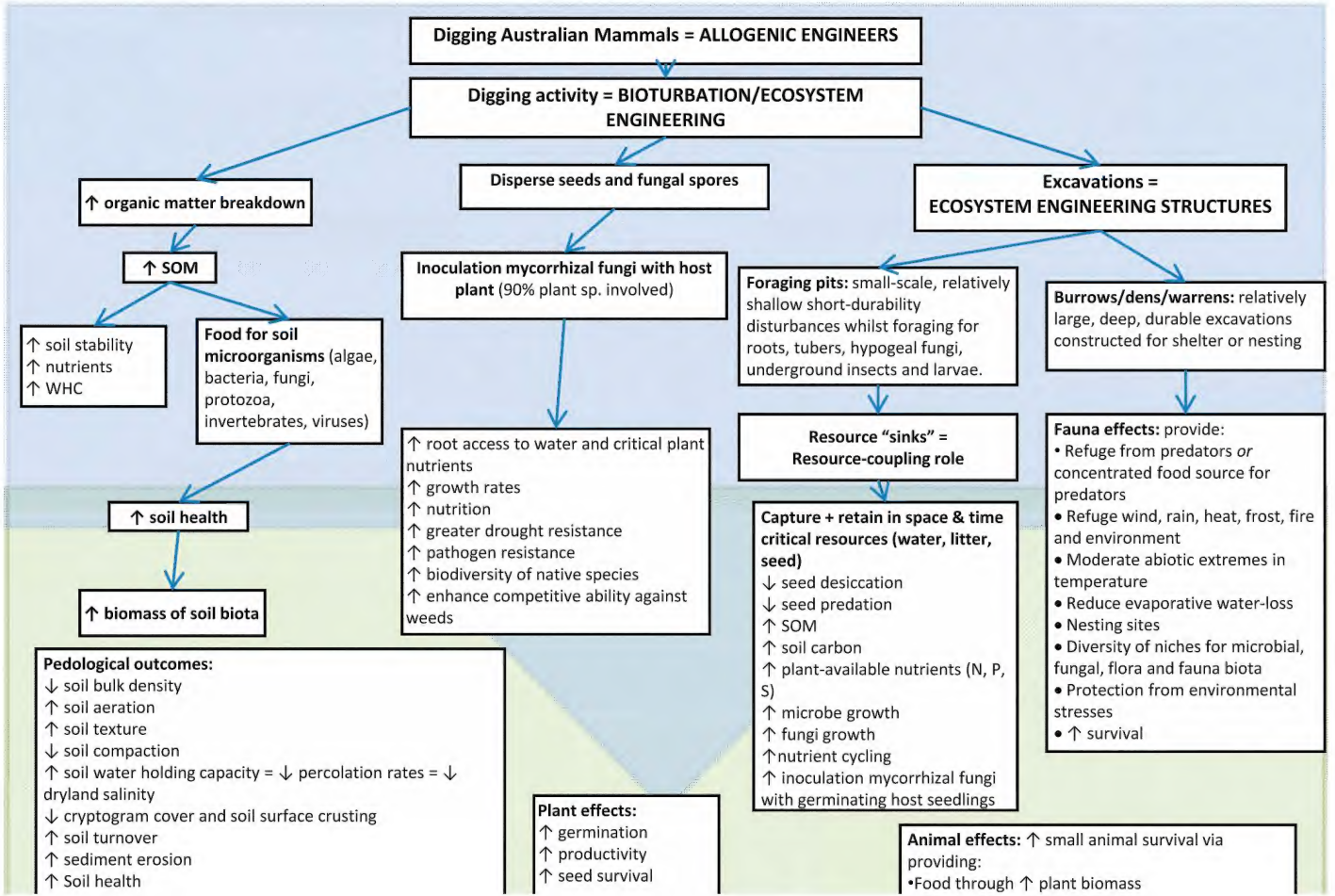
* Conservation status based on International Union for Conservation of Nature Red List of Threatened Species. Threat categories: CR = Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, DD = Data Deficient, LC = Least Concern.

Table 2. Data from studies conducted on the pedologic effects of Australian eco-engineering mammal species as measured by soil turnover, litter accumulation, soil nutrient concentrations and soil physical properties

Eco-Engineering structure	Species	Body weight (kg)	Soil turnover (t/ha/individual/yr)	Diggings (no/ha)	Litter mass	Soil nutrients	Soil physical properties	Reference
Foraging pits	Short-beaked echidna (*Tachyglossus aculeatus*)	2-7	0.39 – 2.1		> litter (2x ↑) > decomposition	< N, S, P, EC within pits under canopies > EC within pits in the open	> erosion > moisture, steady-state infiltration, sorptivity < bulk density < infiltration > CO_2, temp > respiration	Eldridge and Kwok 2008; Eldridge and Mesinga 2007; Newell 2008
	Greater bilby (*Macrotis lagotis*)	0.8-2.5	1.27 – 5.99 (max.30)	7120 (swale) – 10, 560 (mulga) ha^{-1}, or 120 individual^{-1} ha^{-1}	> litter	> C, N, S, LC	> infiltration	James 2004; James and Eldridge 2007; Newell 2008
	Southern brown bandicoot (south-west WA subspecies) (*Isoodon obesulus fusciventes*)	0.4-1.6	2.4 (tonnes / individual / kg body mass/ yr)					Valentine *et al.* 2013
	Eastern Barred Bandicoot (*Perameles gunni*)	0.5-1.45	2.2					Mallick *et al.* 1997
	Burrowing bettong (*Bettongia lesueur*)	1.5	1.27 – 5.99	7120 (swale) – 10, 560 (mulga) ha^{-1}, or 120 individual^{-1} ha^{-1}	1.27 – 5.99	> NH_e^+/ NO_3^-	> moisture	Huang 2007; Newell 2008

	Brush-tailed Bettong (*B. penicillata*)	1.1-1.6	2.6 – 9.7 (woodlands) 8.0 (sandy Swan Coastal Plain)	20-100 individual^{-1} ha^{-1} night^{-1}			> topsoil infiltration	Garkaklis *et al.* 1998; Garkaklis *et al.* 2004; Umbrello 2010
	Tasmanian bettong (*B. gaimardi*)	1.7-2.2		500 – 3000 per ha^{-1}				Johnson 1994a; 1994b
	Long-nosed potoroo (*Potorous tridactylus*)	0.66-1.64		2250 ha^{-1} yr^{-1}				Claricge *et al.* 2003
Burrows and mounds	Southern hairy-nosed wombat (*Lasiorhinus latifrons*)	19-32	2.6 – 87.5					Steele and Temple-Smith 1996
	Common wombat (*Vombatus ursinus*)	22-39	1.72 – 9.8				> BD	Triggs 1996
	European rabbit (*Oryctolagus cuniculus*) (introduced)	1.3-2.2	0.83 – 29.4		< litter	>pH, EC, Ca, K, Al, B, Mn, Fe, sol Na < C, S > N	> clay, bare ground < aggregate stability < cryptogam > temp, RH > infiltration	Eldridge and Myers 2001; Eldridge and Kwok 2008; Eldridge and Koen 2008; Myers *et al*, 1994

C = carbon; N = nitrogen; S = sulfur; LC = labile (active) carbon; NH_e^+/NO_3^- = ammonium/nitrate; P = phosphorus; EC = electrical conductivity; Ca = calcium; K = potassium; Al = aluminium; B = boron; Mn = magnesium; Fe = iron; sol Na = soluble sodium; BD = bulk density; RH = relative humidity


Digging Australian Mammals = ALLOGENIC ENGINEERS
Digging activity = BIOTURBATION/ECOSYSTEM ENGINEERING
↑ organic matter breakdown
Disperse seeds and fungal spores
Excavations = ECOSYSTEM ENGINEERING STRUCTURES
↑ SOM
↑ soil stability
↑ nutrients
↑ WHC
Food for soil microorganisms (algae, bacteria, fungi, protozoa, invertebrates, viruses)
↑ soil health
↑ biomass of soil biota
Pedological outcomes:
↓ soil bulk density
↑ soil aeration
↑ soil texture
↓ soil compaction
↑ soil water holding capacity = ↓ percolation rates = ↓ dryland salinity
↓ cryptogram cover and soil surface crusting
↑ soil turnover
↑ sediment erosion
↑ Soil health
Inoculation mycorrhizal fungi with host plant (90% plant sp. involved)
↑ root access to water and critical plant nutrients
↑ growth rates
↑ nutrition
↑ greater drought resistance
↑ pathogen resistance
↑ biodiversity of native species
↑ enhance competitive ability against weeds
Plant effects:
↑ germination
↑ productivity
↑ seed survival
Foraging pits: small-scale, relatively shallow short-durability disturbances whilst foraging for roots, tubers, hypogeal fungi, underground insects and larvae.
Resource "sinks" = Resource-coupling role
Capture + retain in space & time critical resources (water, litter, seed)
↓ seed desiccation
↓ seed predation
↑ SOM
↑ soil carbon
↑ plant-available nutrients (N, P, S)
↑ microbe growth
↑ fungi growth
↑nutrient cycling
↑ inoculation mycorrhizal fungi with germinating host seedlings
Burrows/dens/warrens: relatively large, deep, durable excavations constructed for shelter or nesting
Fauna effects: provide:
• Refuge from predators or concentrated food source for predators
• Refuge wind, rain, heat, frost, fire and environment
• Moderate abiotic extremes in temperature
• Reduce evaporative water-loss
• Nesting sites
• Diversity of niches for microbial, fungal, flora and fauna biota
• Protection from environmental stresses
• ↑ survival
Animal effects: ↑ small animal survival via providing:
•Food through ↑ plant biomass

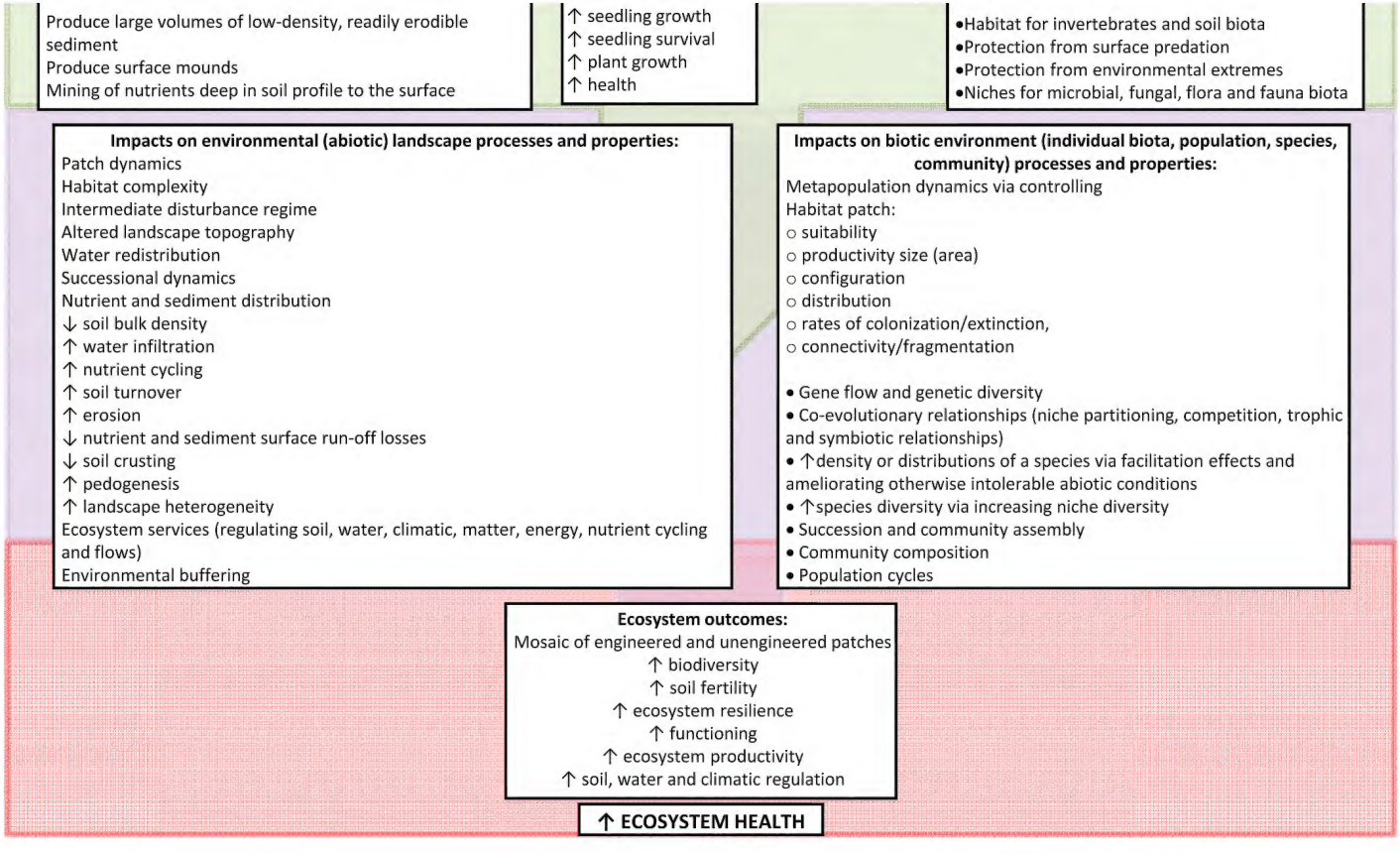


Figure 1. Conceptual flow-chart diagramming how allogenic ecosystem engineering by Australia's digging mammals influences various abiotic and biotic properties of ecosystems at various scales to overall increase ecosystem health.Interactions can be multidirectional and feed-back upon the ecoengineeringanimal. SOM = Soil organic matter, N = plant-available nitrogen, P = plant-available phosphorous, S = plant=available sulfur, WHC = water-holding capacity.

soil-surface properties via digging activity has disproportionately significant effects on plant communities since by creating fertile sinks via concentrating organic matter, moisture and seeds, pits promote germination by becoming foci of enhanced nutrient levels, plant-available N and C, and prevent seedling desiccation and predation (James *et al.* 2009, James and Eldridge 2007). Consequently, Australian digging mammals have a disproportionately significant influence on the landscape. Such mammals critically influence their environment by modifying resources and contributing to land, soil and water quality and processes (Whitford and Kay 1999, Wilby *et al.* 2001).

LOSS OF NATIVE DIGGING MAMMALS LEADS TO DECLINES IN ECOSYSTEM HEALTH

The extinction of diverse megafauna by Aborigines ~50kya resulted in considerable damages to Australia's entire ecosystems, leaving a land depauperate in large, mobile ecosystem engineers and large keystone carnivores (Rule *et al.* 2012). More recently, following European settlement approximately two centuries ago, the Australian environment has suffered declines in ecosystem health, soil productivity, and biodiversity; these have been coincidental with severe declines and extirpations of native mammals. In fact, Australia holds the global record of the greatest number of documented mammal extinctions over the last 200 years (Lindenmayer and Burgman 2005). Most of these threatened or extinct species are fossorial or semi-fossorial (Table 2) (Burbidge and McKenzie 1989, Burbidge 2004, Morton 1990, Short and Smith 1994). Today, many species once common and widespread are restricted to small, isolated populations (Table 1), mainly within reserves surrounded by fences excluding introduced predators (foxes and feral cats). Even where species persist, many have been reduced to such low densities that they are in effect "ecologically extinct." (Estes *et al.* 1989). Causes proposed to be implicated in extinctions and declines are mainly habitat loss, degradation and fragmentation (largely owing to the unnecessary practice of livestock production); altered fire regimes; introduced species (predators, competitors and invasive ecosystem engineers); and interactions between these: all threatening processes linked to land management systems and exotic animals imposed upon the land that accompanied the arrival of Europeans (Burbidge 2004, Lindenmayer and Burgman 2005, Morton 1990).

Historical and experimental evidence implicates the decline in distribution, abundance and extinction of native ecosystem engineering mammalian digging

species with the degradation of Australia's ecosystem health and deterioration of soil quality (James and Eldridge 2007, Martin 2001, Martin 2003). It follows that reintroductions and translocations to increase population sizes can play an important role in restoration projects. Thus, the task of conservation of Australia's native burrowing mammals, via captive breeding, humane predator control, appropriate fire management and translocations, assumes even greater importance. Not only are reintroductions important to increase the viability of these species but also are important to increase the viability of whole ecosystems (Fig. 2).

CONTROVERSY OVER INTRODUCED DIGGING MAMMALS

Loss of native digging mammals following European settlement has been accompanied by invasion and range expansion of non-native ecosystem engineers, namely the European rabbit (*Oryctolagus cuniculus*); today much of the land previously occupied by native burrowing marsupials such as the formerly widespread bilbies and bettongs is now occupied by the similarly-sized introduced rabbit (Burbidge and McKenzie 1989, Courchamp *et al.* 2003, Myers *et al.* 1994, Cooke 2012, Eldridge and Koen 2008, Eldridge and Simpson 2001). Studies have reported pits dug by native bilbies and bettongs have markedly different impacts upon soil and ecosystem properties than those dug by the similar-sized rabbit (Eldridge and Simpson 2002, Eldridge and Simpson 2001, Burbidge and McKenzie 1989, Courchamp *et al.* 2003, Myers *et al.* 1994) (Table 1, 2). However, opinions regarding rabbits as invariably detrimental ecosystem engineers are not unanimous. Different researchers have produced different conclusions regarding rabbit ecosystem engineering. Some researchers advised severe reductions in landscape quality and subsequent biodiversity could result from eradication of rabbits and that rabbits have assumed the important role of ecosystem engineering extirpated native fossorial mammals. For example, Read *et al.* (2008) stated: "the introduced European rabbit may have replaced the role of native burrowers" (p. 2124), and "rabbit warrens have replaced the role of bettong and bilby warrens" (p. 2129).

It can be concluded there is not a simple dichotomy between introduced rabbits as ubiquitously detrimental ecosystem engineers vs. native mammals having ubiquitously positive ecosystem engineering outcomes on their environments. James *et al.* (2009) found fertile patches are created and maintained by bioturbation regardless of whether the excavating species was a rabbit or native species; foraging pits produced by rabbits and native species both effec-

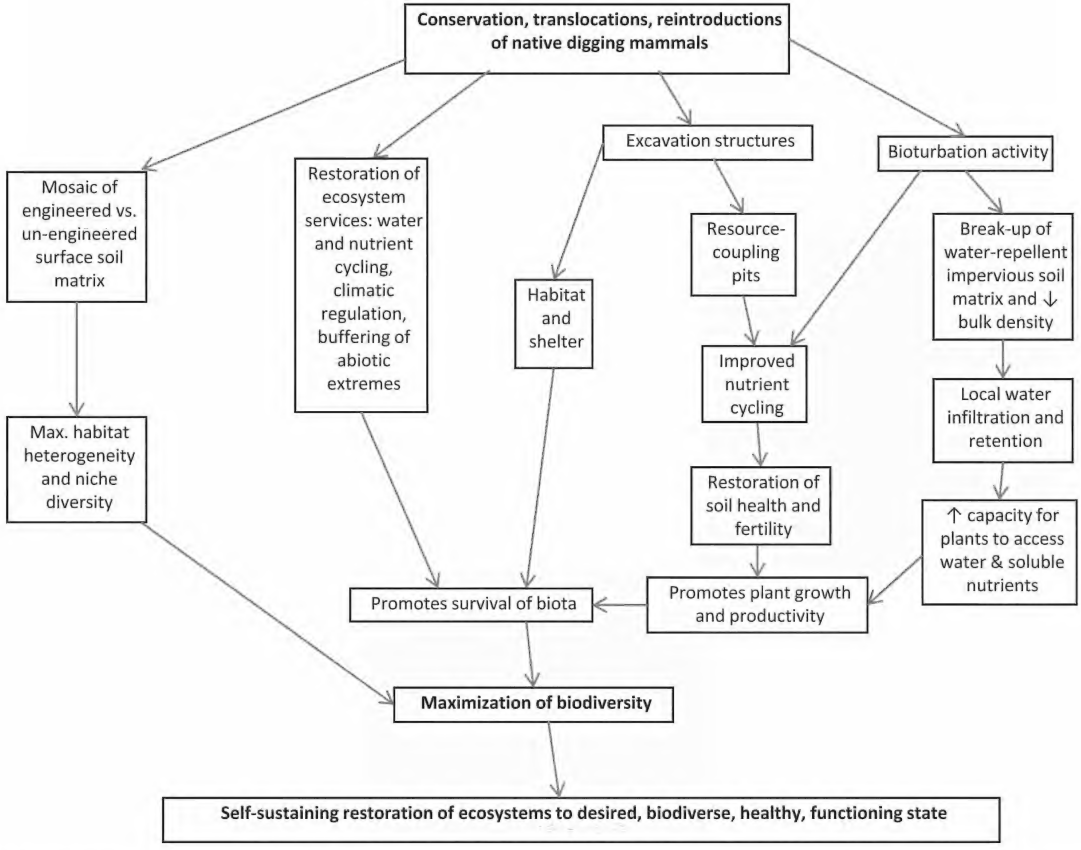


Figure 2. Model for restoring Australia's ecosystems to a desired state and preserving biodiversity by harnessing ecosystem services afforded by native digging mammals. Through altering abiotic conditions, ecosystem engineers act as keystone species, with native species restoration and conservation facilitating restoring ecosystems to a desired, healthy state and promoting biodiversity.

tively trapped litter and seed and created microenvironments with consistently greater germination than the surrounding "unengineered" landscape. There has been documentation of widespread, extensive use of both below- and above-ground features produced by rabbits by native vertebrates and invertebrates. For example, rabbits warrens refuge echidnas, burrowing bettongs, Mulga Snakes (*Pseudechis australis*), pythons, skinks, geckos, birds, domestic cats (*Felis catus*), Red Foxes (*Vulpes vulpes*), Dingos (*Canis familiaris dingo*) and ants (genera *Melophurus*, *Rhytidoponera*, *Iridomyrmex* and *Camponotus*) are more abundant on rabbit warrens (Heard *et al.* 2004, Read *et al.* 2008, Robley *et al.* 2002, Turner 2004, Wilkinson *et al.* 1998). Moreover, the higher, concentrated abundance of small animals (invertebrates and vertebrates) likely provides a valuable food source for sympatric carnivores.

This has implications for management schemes aimed at eradicating rabbits and warren ripping. Rather than improving biodiversity, eradicating rabbits can lead to further declines in Australia's native biota owing to the role rabbit burrows play in providing habitat and refuge from environmental pressures (wind, temperature, evaporative water-loss, predation). Moreover, rabbits may now comprise a major food source for many native predators, including raptors, reptiles, carnivorous marsupials and the dingo (Prins and Gordon 2014). Another unintended detrimental consequence arising from rabbit eradication includes increased predation of native prey – including already imperilled native digging mammals – by predatory species (native and/or non-native) prey-switching and increasing predation on native species following rabbit declines (Doherty *et al.* 2015).

Nevertheless the majority of researchers and reviews conclude that at high densities rabbits are major agents involved in overall landscape degradation in Australia, particularly at the soil-surface level (Cooke 2012). Rabbits also are not perfect replacements of native ecosystem engineers, whose ecosystem engineering would have been superior in their effects on ecosystem health. This relates to differing lifestyles and excavation characteristics of rabbits vs. burrowing marsupials (Tables 1, 2). Comparing areas where native mammals have been reintroduced in fenced, rabbit-free reserves vs. adjacent areas where rabbits exist in the absence of native mammals, James and Eldridge (2007) found that across all soil types (dunes, swale and intervening ecotones) "all engineers are not equal." (p. 357) Likewise, James *et al.* (2011) reported rabbits have not assumed the role of native equivalents (bilbies and bettongs), with the invasive specie's

ecosystem engineering effects being inferior in comparison. Overall, it appears rabbits have not replaced the critical role of native engineers (Cooke 2012). Having co-evolved with native mammalian digging species, it is likely that Australia's biotic communities are adapted to the disturbance regime created by native mammal's bioturbation activity and biota exist in a mutualistic or commensal relationship with native mammals. In contrast, native communities are less likely to thrive in the modified habitat created under the novel disturbance regime imposed by the recent introduced ecosystem engineering rabbits.

CONSIDERATIONS FOR FUTURE STUDIES AND RESTORATION PROJECTS

Future studies are needed to quantify how density of each species impacts upon soil characteristics. This is important in order to set targets so that species are maintained at densities not only viable to prevent extinction but to ensure they can effectively perform their ecosystem engineering services. Below certain densities ecosystem engineers may be unable to have measurable impacts upon facilitating soil cycling or life cycles of native animals and plants adapted to living in habitats engineered by these species.

Quantifying how density affects ecosystem properties is also important because at high densities desirable outcomes may give-way to ecosystem degeneration, e.g. excessive soil turnover rates and destruction of cryptogram cover leading to damaging levels of erosion (Byers *et al.* 2006, Gutterman 1997, Wilby *et al.* 2001). Further studies should also investigate if different species or suites of species produce different ecosystem engineering effects. Differences in species activity levels, foraging strategies, pit morphology, and digging types (productions ranging from dens, warrens, burrows, foraging pits, shallow scrapes, conical pits, nose-pokes) produce different soil and ecosystem outcomes. It follows that maximum biodiversity will be achieved only when ecosystem engineering guilds of a diversity species – creating maximum temporal and spatial diversity in ecosystem engineering effects across a region – are present at ecologically significant densities. The greater ranges of dig dynamics – temporal (duration) and spatial (location) – and morphologies (depth, aperture, size, shape, volume, orientation) will provide a greater range of habitat attributes (moisture, temperature, nutrient concentrations, litter capture). This in turn provides a greater diversity of biological niches to which different organisms are optimally adapted.

Due to the facilitatory effect of native species in providing refuges for introduced predators

(cats, foxes) and competitors (rabbits, mice), and their beneficial ecosystem engineering effects on landscape productivity in supporting livestock – recognized as imposing major threats to Australia's native biodiversity – native ecosystem engineers may have inadvertently contributed to their own demise (Lindenmayer and Burgman 2005). Pedogenic consequences of burrowing activity by native ecosystem engineering mammals favours establishment of swards of highly palatable perennial grasses, with the nutritious herbage promoted in the vicinity of the native mammal diggings supporting a suite of feral and domesticated herbivores. The thermal and hydrological microclimate within warrens of bettongs and wombats themselves provides habitat and enables many other species to survive the rigors that desert environments impose. Yet burrows produced by wombats, bilbies and Burrowing Bettongs provide shelter and nursery dens facilitating rabbits, cats, and foxes to persist in harsh arid areas (Cooke 2012). Native burrows likely greatly facilitated the rapid and successful spread and invasion of rabbits following their initial introduction; Burrowing Bettong warrens in particular appear to have enabled rabbits to invade even hot areas with hard soils where survival of rabbits would otherwise be prevented, facilitating rabbit invasions into Australia's otherwise inhospitable ecosystems (Aitken 1971, Burbidge *et al.* 2007, Coman 1999, Parer and Libke 1985).

Given experiments demonstrating greater soil nutrients and other indexes of soil health in soils worked by rabbits than without (James *et al.* 2011), and how rabbit warrens provide habitat, refugia and promote survival of certain native plant and animal species (e.g. brushtail possums, echidnas, diverse reptiles, and numerous insects (Read *et al.* 2008), it appears complete absence of bioturbating mammals occupying an ecosystem engineering niche will produce even more undesirable consequences (Zavaleta *et al.* 2001). This conclusion is supported by the unanticipated deleterious effects whereby eradication of introduced rabbits from some islands has enabled invasive plants and rats to dominate and impede recovery of native island fauna (Abbott *et al.* 2000, Bullock *et al.* 2001, Lees and Bell 2008, North *et al.* 1994). Quantifying levels at which effects of rabbits do not translate into measurable impacts considered to detriment soil health may be important. This is because intensive eradication incurs numerous costs and concerns. These include costs in terms of finances, technology and resources, time and personnel; ethical issues associated with control methods and risks of harming non-target species; loss of refuges that warrens offer for

sympatric non-burrowing native species; lack of disturbance from rabbit ecosystem engineering activity causing further declines in ecosystem health; and, despite occurring at lower densities, greater predation from introduced predators (cats and foxes) upon already reduced populations of native species (Cooke 2012). Thus, costs may far outweigh benefits of intensive eradication regimes and controlling rabbits at tolerable densities may be more suitable.

Rather than continue inhumane mass culling of all "feral" species, which can lead to more harm than good owing to complex interactions that characterise ecosystems, efforts should be directed at humane control. What is most crucial however is to boost population sizes of native ecosystem engineers so that they can co-exist with these newly arrived species. Enhancing populations of native ecosystem engineers can be achieved by captive breeding, reintroductions, translocations, and reclaiming and rehabilitating land currently used for livestock grazing, thereby restoring native species to these now-degraded landscapes.

Co-opting ecosystem engineering species in restoration projects offers a cheaper, easier, faster, and more sustainable means to restore degraded ecosystems compared with alternatives that fail to include native digging mammal introductions (Byers *et al.* 2006). My review supports importance of conserving and reintroducing native engineering species to their former ranges and densities so that they can fulfil the ecosystem engineering niche left vacated following their disappearance from much of Australia's landscapes.

RESTORING ECOSYSTEM HEALTH THROUGH RESTORING NATIVE MAMMALIAN ECOSYSTEM ENGINEERS

Abundant evidence (both observation and experimental) and reviews confirm the critical role to fertile patch creation, biodiversity and productivity, and overall ecosystem health native ecosystem engineering mammals impart to Australia's drylands. Studies demonstrating positive, unique impacts of native ecosystem engineering playing a critical role in maintaining resilient, functional ecosystems further emphasises importance of conservation programmes for Australia's native burrowing mammal species and their reintroduction into former habitat.

It is evident that ecosystem engineering species are vital for maintaining a suite of ecosystem processes and contributing to ecosystem health (Fig. 1) (Prendergast 2012). Bioturbation by native ecosystem engineering mammals, via modifying abiotic environmental variables and resources, influences Australia's populations of flora and fauna,

biotic communities, biotic and abiotic interactions, ecosystem functioning and landscape structure. Whilst native digging mammal extirpation and reductions are likely a key factor implicated in ecosystem degradation, re-introductions and supplementary translocations hold great potential to enable successful, ongoing, cost-effective ecosystem restoration (Fig. 2) (Byers *et al.* 2006). The potentially beneficial role reintroductions of digging mammals can play in ecosystem restoration has already been demonstrated. To facilitate restoration of Australia's arid ecosystems, an innovative trial reintroducing the Greater Bilby *Macrotis lagotis* and Burrowing Bettong *Bettongia lesueur* into areas from which they had become extirpated has been hailed as preliminary successful (Newell 2009). Brush-tailed Bettong reintroductions into Lincoln National Park (South Australia) conducted as part of a regional restoration program were initially successful however lack of fox and cat baiting resulted in numbers then decreasing (Martin *et al.* 2006). Similar declines in other reintroduction projects have occurred in the absence of predator control, highlighting the necessity of considering predator density at reintroduction sites or safeguarding reintroduced species (e.g. through predator-proof fencing). The caveat therefore is that threatening processes leading to the demise of native digging mammals must also be addressed if ecosystem engineering species are to re-establish, persist and successfully perform their role in ecosystem services.

CONCLUSION

Published data evince how native Australian mammals improve soil quality and ecosystem processes, and how following reintroductions this has positively altered the number and distribution of fertile patches across landscapes. Therefore to achieve resilient, biodiverse and sustainable ecosystems, restoration programmes should focus attention upon restoring the linkages between these native digging mammals and their ecosystem engineering processes. Despite substantial challenges to restoring native mammals to their former distribution and abundance, this task is fundamentally important. Investing in restoration projects on wider, realistic scales is highly desirable.

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FLORA OF THE SWAN COASTAL PLAIN FOOTHILLS PART 1: VASCULAR FLORA OF LAMBERT LANE NATURE RESERVE

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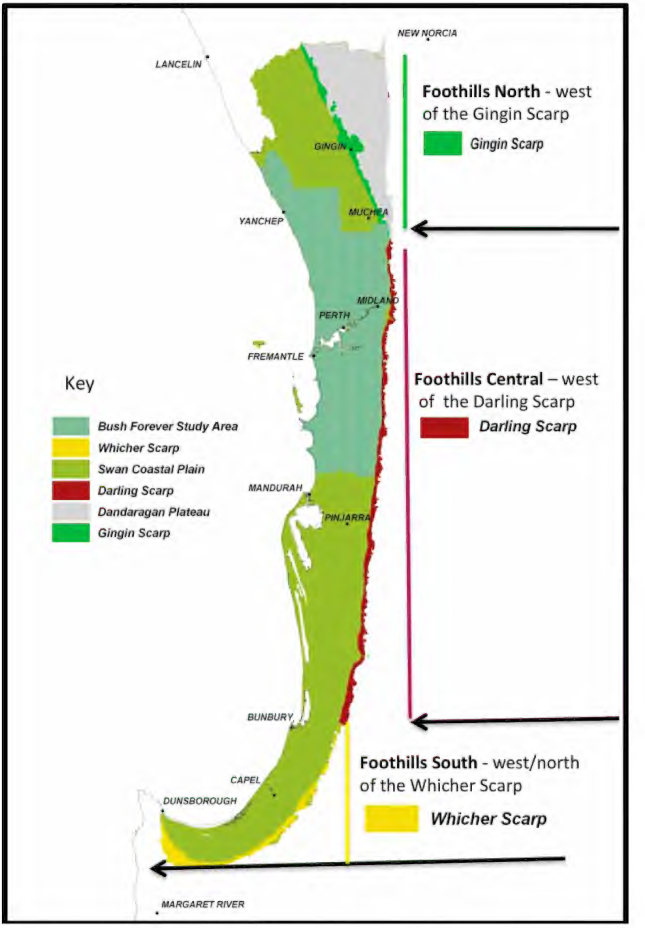
ABSTRACT

With less than 3% of intact vegetation remaining, the Ridge Hill Shelf is the most cleared geomorphological unit of the Swan Coastal Plain. Lambert Lane Nature Reserve, a small four hectare bushland remnant just south of Armadale in Western Australia contains Salmon White Gum dominated woodland of the Foothills landform unit. This tiny remnant has a vascular flora of 238 species (208 native species, 30 weeds), and is one of the few intact examples of Salmon White Gum dominated vegetation remaining.

INTRODUCTION

The Foothills, or Ridge Hill Shelf (Macarthur and Bettenay 1960, Government of WA 2000) of the Swan Coastal Plain IBRA region (SWA, Department of Environment and Water Resources 2007) are the gentle seaward slopes along the Gingin, Darling and Whicher Scarps. The soils of the Foothills have a complex layering of: sand from an old beach ridge; colluvial sands, loams and clays; and gravel. The order and the number of layers varies with the location. Three Foothills sectors can be distinguished, based on the adjoining scarp, which is the origin of the colluvial soils (Figure 1).

- Northern Foothills, or Coonambidgee landform unit (Macarthur and Bettenay 1960), parallel to the Gingin Scarp from the Moore River at Regans Ford to Bullsbrook. The Dandaragan Plateau (IBRA sub-region SWA1) is to the east and the Swan Coastal Plain (IBRA sub-region SWA2) to the west. The colluvium is derived from the Dandaragan Plateau.
- Central Foothills, or Forrestfield landform unit (Macarthur and Bettenay 1960), between Bullsbrook and Burekup the colluvial soils derive from the Darling Plateau and abut the granitic slopes of the Darling Scarp.



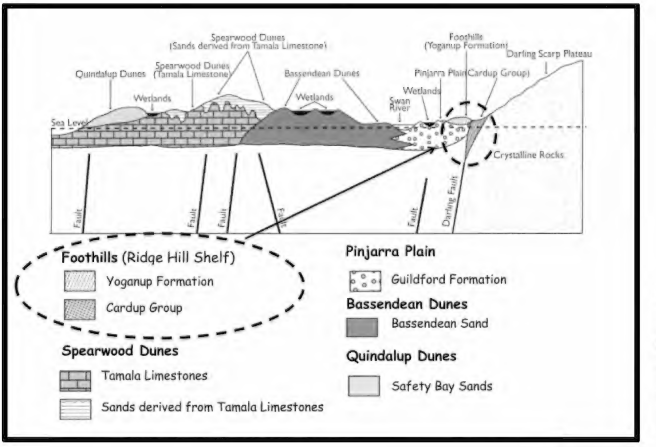


Figure 1. Location of the Ridge Hill Shelf Geomorphological Unit (After Keighery *et al.* 2008 and Macarthur and Bettenay 1960).

- Southern Foothills from Burekup to Dunsborough, parallel to the Whicher Scarp. This section of Foothills is poorly defined but colluvium is derived from the Blackwood Plateau.

While the origin of the colluvium in the Foothills varies, the sands of the old beach ridge (formed when higher sea levels of the Pleistocene reached the base of the scarp) are common to full extent of the Foothills. These sands are the origin of the mineral sands for which the Foothills are highly prospective.

Over its entire range the Foothills have very high levels of clearing for agriculture being of low relief, relatively fertile and better drained than the seaward Pinjarra Plain. It is estimated that the Foothills are over 97% cleared, making any remnant of high regional conservation value.

South of Armadale (Figure 1) the Darling Scarp becomes a gentler relief and this geomorphic feature and its adjacent foothills has also been almost totally cleared, before any detailed flora survey was conducted. The aim of this series of papers is to

Figure 2. Location of Lambert Lane Nature Reserve (Google Earth and Metropolitan Street Directory).

compile lists of the flora of the accessible intact remnants of natural bushland present on the Central Foothills from Armadale to Harvey with Salmon White Gum (*Eucalyptus lane-poolei*) or Mountain Marri (*Corymbia haematoxylon*) as dominants in the area. These remnants (Lambert Lane Nature Reserve, Bancell Road Reserve and Korijekup Conservation Park) are significantly different from each other, and listing each area's flora helps develop a better picture of the diversity of plant communities associated with this restricted and diverse landform. A concluding paper will draw together all available information on the flora of the entire unit.

Lambert Lane Bushland (Bush Forever Site 264) is a small area of reserves located in the City of Armadale (Figure 2). Lambert Lane Nature Reserve (Lambert Lane NR), Fletcher Park and bushland in road and rail reserves form this Site. The area of mapped bushland in the Site is around 8.3 ha, of which about four hectares is encompassed in the Lambert Lane NR. This is one of the very few remaining stands of Salmon White Gum, that were once a feature of the eastern Swan Coastal Plain of the Serpentine (Keysbrook-Mundijong-Byford) area (Powell 1990, Figure 3).

Figure 3. *Eucalyptus lane-poolei* woodland in Lambert Lane Nature Reserve (B.J. Keighery).

SURVEY METHOD

Survey work in Lambert Lane NR was performed over many flowering seasons from 1991 to 2014. Opportunistic plant collections, that is, collections made outside set study points (quadrats), were made during foot traverse at various times of the year. Two relevees were described from the Bush Forever Site by Keighery and Trudgen (1992) and two permanently marked quadrats were located in the Lambert Lane NR and sampled as part of the Gibson *et al.* study (1994, Lamb 01 and 02). Voucher collections are deposited in PERTH.

Nomenclature generally follows that used in Florabase (Western Australian Herbarium 1998–), or in the most recent revisions. The distinctive form of Jarrah (*Eucalyptus marginata* subsp. *elegantella*) that occurs on the Ridge Hill Shelf is recognised in this report. Conservation status of the flora is assigned in Smith (2014).

GEOMORPHOLOGY AND SOILS

Lambert Lane NR has colluvial deposits of sands and clays with lateritic pebbles deposited by water erosion of the granites of the Darling Scarp (Figure 1). Much of the Site is waterlogged in winter/spring though dry in summer. The southern wetter areas of the Site are mapped as Conservation Category wetland.

VEGETATION

The vegetation at Lambert Lane NR is mapped as part of the Forrestfield complex (Beard 1979 and Heddle *et al.* 1980), which occurs along the foothills of the Darling Scarp. Lambert Lane NR was also sampled in two regional surveys. First in 1991 as part of the eastern side of the Swan Coastal Plain (Keighery and Trudgen 1992) and in 1992/3 as part of a regional floristic survey of the Swan Coastal Plain (Gibson *et al.* 1994). Both studies identified this area as being part of unique vegetation of the Foothills. Gibson *et al.* (1994) placed the vegetation in Swan Coastal Plain floristic community type (SWAFCT) 3a, which is wetland/dampland unit of the Eastern side of the Swan Coastal Plain.

The uniqueness of this vegetation compared to that of the Darling Scarp was further confirmed in the Darling Scarp study by Markey (1997).

A further regional floristic study of the Whicher Scarp and adjacent Swan Coastal Plain (Keighery *et al.* 2008) supported the separation of the Darling and Whicher Scarps north of Dardanup. Regional site descriptions of actual and potential reserves in the foothills in the Perth Metropolitan Region were given in Bush Forever (Government of Western Australia 2000).

The Bush Forever Site description of site number 264 (Government of Western Australia 2000)

gives the vegetation of Lambert Lane as *Eucalyptus calophylla* and *E. lane-poolei* Low Open Woodland over mixed open heath.

Salmon White Gum occurs as a series of largely disjunct populations between Mount Lesueur and the Whicher Range (south of Busselton). The northernmost populations (north of the Moore River) are small and have a typical lateritic heath understory. A second isolated occurrence is on the slopes of the Dandaragan Plateau escarpment on orange sands in Boonanarring Nature Reserve, north of Gingin. The southernmost occurrence of Salmon White Gum in the Whicher Range is composed of isolated trees that do not form a vegetation layer (Keighery *et al.* 2008). Between these outliers Salmon White Gum woodlands are found on colluvial loams and clays of the Forrestfield complex and Darling escarpment or on Darling Scarp granites between Gosnells and Karnet.

Gibson *et al.* (1994) placed these woodlands in their Super group *Corymbia calophylla-Kingia australis* woodlands on heavy soils. This community is now State and Federally listed as a Threatened Ecological Community. Subsequently to this study in the regional floristic assessment of the northern Darling Scarp, Markey (1997) placed woodlands of *Eucalyptus lane-poolei* in Community types 4, 5 and 7. These are:

- Community type 4: Woodlands on steep colluvial slopes of scarp face and upper valleys.
- Community type 5: Central Granite Shrublands.
- Community type 7: Woodlands on poorly drained colluvial deposits.

The final community type is a close match for the woodlands at Lambert Lane, linking these woodlands to the Ridge Hill Shelf rather than the Pinjarra Plain centred *Corymbia calophylla* woodlands.

The areas recommended for reservation of this community on the Forrestfield complex in the System Six Study (Department of Conservation and Environment 1983, area M 88), which were in 1983 already partly cleared, now appear to have been developed for agriculture and only scattered trees remain with no intact understory.

There are several other small areas of Salmon White Gum woodland that correspond to Markey's (1997) community type 7 remaining in Brickwood Reserve (Keighery and Keighery 1993b), Norman Road Bushland (BF site 354, Government of Western Australia 2000), Fairbridge Farm and scattered along the Byford to Serpentine rail/road reserves (BF sites 350, 365, 375). Lambert Lane NR is perhaps the largest remnant of this woodland type remaining.

FLORA

We recorded a total of 238 species of vascular plant (208 natives, 30 weeds) in Lambert Lane NR

distributed in 43 families. Major groups are the Asparagaceae (20 species), Fabaceae (19), Proteaceae (18), Cyperaceae (17) and Myrtaceae (13). Largest genera are *Acacia* (9), *Stylidium* (8), *Hakea* (7) and *Drosera* (7).

This is a species rich flora comparable with other sites on the Ridge Hill Shelf/Pinjarra Plain of the Swan Coastal Plain. For example, the nearby Brickwood Bushland (Keighery *et al.* 1993b) has 309 natives in 43 ha., and Talbot Road Bushland (Keighery *et al.* 1993a) in the Shire of Swan, but on the Ridge Hill Shelf, has 366 natives in 90 ha. As frequently encountered in the flora of south-west Western Australia considerable change-over occurs between areas with only 132 (38%) of the 349 species of the combined floras of Lambert Lane NR and Brickwood Bushland being shared.

Rare and Priority Flora

Stylidium squamellosum

A priority two species with scattered records from near Kojonup north to near Muchea in Barracca Nature Reserve (Keighery *et al.* 2013). Previously the only record from a conservation reserve was the record from Barracca Nature Reserve.

Significant Species

Lambert Lane NR contains a series of species only known from the Swan Coastal Plain Bioregion from occurrences on the Ridge Hill Shelf: *Acacia latericola*, *Acacia drewiana* subsp. *drewiana*, *Beaufortia macrostemon*, *Chamaescilla versicolor*, *Chorizema dicksonii*, *Eucalyptus marginata* subsp. *elegantella*, *Grevillea wilsonii*, *Melaleuca radula*, *Patersonia rudis* subsp. *rudis*, *Stylidium* sp. Darling Range, *Synaphea acutiloba* and *Synaphea* sp. Pinjarra. These species are typically found on the laterites and granites of the adjacent Jarrah Forest Bio-Region and do not occur west on the swamps and sands of the coastal plain. These species link the flora of the reserve to the Community type 7: Woodlands on poorly drained colluvial deposits.

The reserve also contains a series of species that are only recorded for the Swan Coastal Plain on heavy soils of the eastern side of the Swan Coastal Plain, that is, normally on rises in the alluvial soils of the Pinjarra Plain. These are: *Gahnia ancistrophylla*, *Schoenus andrewsii*, *Calectasia grandiflora* and *Conostylis caricina* subsp. *caricina*. These species link the flora of the reserve to the Super group *Corymbia calophylla-Kingia australis* woodlands on heavy soils, described in Gibson *et al.* (1997).

These two groups of species distinguish Lambert Lane NR from all other bushland remnants of the Ridge Hill Shelf.

Weeds

The most serious weeds present in Lambert Lane NR are South African cormous and bulbous species. Baboon Flowers (*Babiana angustifolia*) are already wide-

spread in low numbers throughout the reserve, unusually containing a large number of white flowered plants. This species will dominate the ground flora unless controlled. Other serious geophytic weeds present are *Romulea rosea*, *Sparaxis bulbifera*, *Watsonia meriana* var *bulbillifera* and *Oxalis glabra*.

The invasive perennial grasses, *Eragrostis curvula* and *Ehrharta calycina* are currently largely restricted to the disturbed edges of the reserve, where they could be eradicated. Whereas the annual grasses, *Avena barbata*, *Briza maxima* and *B. minor*, although mostly in the highly disturbed area around the old rubbish tip, where control would greatly reduce their populations, are now scattered throughout the reserve.

DISCUSSION

We consider that over 90% of the known flora of the reserve has been documented. It is possible that infrequent events such as fire may add a few taxa. We expect that the flora of the woodland at Lambert Lane provides an expected base flora list for those remnants of Salmon White Gum that were once a feature of the eastern Swan Coastal Plain of the Serpentine (Keysbrook-Mundijong-Byford) area, however, because of the rapid turnover of species there will be differences between each site.

Because of the very small size of Lambert Lane NR, consolidation of the remainder of the vegetation around the Nature Reserve as proposed (Bush Forever Site 264: including Fletcher Park and bushland in road and rail reserves) in Bush Forever (Government of Western Australia 2000) would buffer and enhance the persistence of this endangered community.

ACKNOWLEDGEMENTS

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Table 1. Vascular Flora of Lambert Lane Nature Reserve

MONOCOTYLEDONS

ASPARAGACEAE
Borya scirpoidea
Borya sphaerocephala
Caesia micrantha
Chaemaescilla corymbosa
Chaemaescilla versicolor
Dichopogon ?capillipes
Johnsonia pubescens
Laxmannia squarrosa
Laxmannia sessiliflora subsp. australis
Lomandra hermaphrodita
L. odora
L. preissii
L. brittanii
L. spartea
L. sericea
Sowerbaea laxiflora
Thysanotus manglesianus
T. thyrsoideus
T. triandrus
Tricoryne elatior

CENTROLEPIDACEAE
Aphelia cyperoides
Centrolepis aristata
C. cephaloformis
C. drummondiana

COLCHICACEAE
Burchardia congesta
B. multiflora

CYPERACEAE
Cyathochaeta avenacea
Gahnia ancistrophylla
Lepidosperma apricola
L. angustatum
L. leptostachyum
L. pubisquameum
Mesomelaena stygia
M. pseudostygia
M. tetragona
Schoenus curvifolius
S. andrewsii
S, grammatophyllus
S. nanus
S. subbulbosus
S. subflavus
Tetraria octandra
Tricostularia neesii

DASYPOGONACEAE
Calectasia grandiflora
Dasypogon bromeliifolius
Kingia australis

HAEMODORACEAE
Anigozanthos humilis
Conostylis aculeata subsp. preissii
C. caricina subsp. caricina
C. juncea
C. setigera
Haemodorum laxum
H. sparsiflorum
H. spicatum

HYPOXIDACEAE
Hypoxis glabella

IRIDACEAE
**Babiana angustifolia*
**Freesia alba x leichtlinii*
Patersonia juncea
P. occidentalis
P. rudis subsp. rudis
**Romulea rosea*
**Sparaxis bulbifera*
**Watsonia meriana* var. *bulbillifera*

ORCHIDACEAE
Caladenia flava subsp. *flava*
C. longicauda
Cyanicula sericea
Diuris corymbosa
**Disa bracteata*
Elythranthera brunonis
Eriochilus dilatatus subsp. undulatus
Microtis media
Prasophyllum drummondii
P. parviflorum
Pterostylis sanguinea
Thelymitra crinita
T. macrophylla
T. vulgaris

PHORMIACEAE
Agrostocrinum hirsutum
Dianella revoluta

POACEAE
**Aira caryophyllea*
Amphipogon laguroides
A. turbinatus
Aristida holathera var. *holathera*
A. ramosa
Austrostipa campylachne
A. compressa
A. trichophylla
**Avena barbata*
**Briza maxima*
**B. minor*
**Eragrostis curvula*
**Ehrharta calycina*
Neurachne alopecuroidea
Rytidosperma acerosa
R. occidentalis

RESTIONACEAE
Anarthria humilis
Desmocladus fasiculatus
D. flexuosus
Hypolaena exsulca
Lepyrodia macra
Lyginia barbata

XANTHORRHOEACEAE
Xanthorrhoea preissii
X. brunonis

DICOTYLEDONS

AMARANTHACEAE
Ptilotus manglesii

APIACEAE
Actinotus leucocephalus
Daucus glochidiatus
Hydrocotyle alata
H. pilifera var. *glabrata*
Trachymene pilosa
Xanthosia ciliata
X. huegelii

ASTERACEAE
Blennospora drummondii
**Dittrichia graveolens*
Hyalosperma cotula
**Hypochaeris glabra*
Lagenophora huegelii
Olearia paucidentata
Millotia myosotidifolia
Pterochaeta paniculata
Rhodanthe citrina
Siloxerus humifusus
S. multiflorus
**Sonchus oleraceus*
Quinetia urvillei
**Ursinia anthemoides*

CAMPANULACEAE
Isotoma hypocrateriformis
Lobelia rhombifolia
Lobelia tenuior
Wahlenbergia preissii

CARYOPHYLLACEAE
**Petrorhagia dubia*
**Silene gallica*

CASUARINACEAE
Allocasuarina humilis
A. microstachya

CELASTRACEAE
Tripterococcus brunonis

CRASSULACEAE
Crassula colorata

DILLENIACEAE
Hibbertia aurea
H. diamesogenos
H. acerosa
H. hypericoides

DROSERACEAE
Drosera erythrorhiza
D. glanduligera
D. heterophylla
D. macrantha subsp. macrantha
D. menziesii subsp. penicillaris
D. porrecta
D. pycnoblasta

ERICACEAE
Astroloma pallidum
Andersonia lehmanniana subsp. pubescens
Styphelia tenuiflora

EUPHORBIACEAE
Poranthera microphylla
Stachystemon vermicularis

FABACEAE
Acacia drewiana subsp. *drewiana*
A. latericola
A. microbotrya
A. nervosa
**A. podalyriiifolia*
A. pulchella var. pulchella
A. saligna
A. sessilis
A. stenoptera
A. teretifolia
Bossiaea eriocarpa
**Chaemaecytisus palmensis*
Chorizema dicksonii
Cristonia biloba
D. decurrens
Daviesia preissii
Gastrolobium capitatum
Gompholobium knightianum
G. marginatum
G. tomentosum
Hovea trisperma
Sphaerolobium medium
**Trifolium angustifolium*
**T. campestre*
**Vicia sativa* subsp. *sativa*

GERANIACEAE
**Erodium botrys*

GOODENIACEAE
Dampiera alata
D. linearis
Goodenia caerulea
G. micrantha
Lechenaultia biloba

LAMIACEAE
Hemiandra pungens

LAURACEAE
Cassytha aurea
C. glabella
C. racemosa

LOGANIACEAE
Phyllangium paradoxum

LORANTHACEAE
Nuytsia floribunda

MYRTACEAE
Babingtonia camphorosmae
Beaufortia macrostemon
Corymbia calophylla
Eremaea pauciflora
Eucalyptus lane-poolei
E. marginata subsp. *elegantella*
E. rudis subsp. *rudis*
Hypocalymma angustifolia
Kunzea micrantha subsp. *micrantha*
**Leptospermum laevigatum*
Melaleuca radula
Verticordia densiflora
V. pennigera

OROBANCHACEAE
**Orobanche minor*
**Parentucellia latifolia*

OXALIDACEAE
**Oxalis glabra*

PAPAVERACEAE
**Fumaria capreolata*

PRIMULACEAE
**Lysimachia arvensis*

PROTEACEAE
Banksia armata var. *armata*
B. dallanneyi var. *dallanneyi*
B. bipinnatifida
Grevillea pilulifera
G. wilsonii
Hakea ceratophylla
H. incrassata
H. lissocarpha
H. ruscifolia

H. spathulata
H. stenocarpa
H. trifurcata
Lambertia multiflora subsp. *darlingensis*
Petrophile striata
Synaphea acutiloba
S. gracillima
S. petiolaris
S. sp. Pinjarra (A.S. George 17182)

RUBIACEAE
Opercularia vaginata

RUTACEAE
Philotheca spicata

SANTALACEAE
Leptomeria cunninghamii

STYLIDIACEAE
Levenhookia pusilla
L. stipitata
Stylidium androsaceum
S. brunonianum subsp. *brunonianum*
S. bulbiferum
S. dichotomum
S. petiolare
S. repens
S. squamellosum
S. sp. Darling Range (H. Bowler 371)

VIOLACEAE
Hybanthus floribundus subsp. *floribundus*

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VARIATION IN *MONOCULUS MONSTROSUS* (ASTERACEAE)

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ABSTRACT

Two distinctive previously undocumented forms of the widespread weed *Monoculus monstrosus* are recorded from Western Australia. This indicates either a much more varied species than previously understood or multiple introductions of one or several taxa could be present in Western Australia.

INTRODUCTION

The genus *Monoculus* (Asteraceae Tribe Calenduleae) is a segregate of *Osteospermum* with 2 species, *Monoculus hyoseroides* (DC.) B. Nord. and *Monoculus monstrosus* (Burm.f.) B. Nord. found in South Africa and Namibia (Nordenstam 2006). One species *Monoculus monstrosus*, which naturally occurs from southern Namibia through the Cape to the Riviersonderend region of South Africa is naturalised in Western Australia, South Australia, Victoria and New South Wales (Ghafoor 2015).

In Western Australia the wind dispersed fruits, unpleasantly scented sticky foliage (which gives the species common name-Stinking Roger) and unpalatable nature of the plant has enabled this species to become a highly invasive annual of numerous vegetation types and soils extending from the coast into the arid interior. The species is also considered weedy in its native South Africa because of its reputed poisonous nature (Bromilow 2001).

In Eastern Australia the species is mainly recorded from sandy soils (Scott and Harding 1992; Short 1999), however, in Western Australia it has mainly invaded areas of higher fertility or in the arid water gaining sites. These include granite rocks (both in the Mediterranean areas and into the arid), woodlands of the Wheatbelt (York Gum, Jam, Morrell and Salmon Gum) and Swan Coastal Plain (Tuart) and salt lake margins in the arid and semi-arid. The species has also been recorded in lower fertility sites such as Jarrah and Banksia woodlands, shrublands and heath, suggesting that it may still be increasing its ecological range.

Despite the widespread distribution and invasive nature of this species very little is known about its effects, probably because it is a slender annual that is relatively inconspicuous compared to the other weedy African daisies such as Cape Weed or Gazania. However, it can obtain large populations in crevices and on moss swards on granite rocks, and in Wheatbelt woodlands where it may be competing directly with other native herbs.

VARIATION

In Australian and South African treatments (Scott and Hardin 1992; Short 1999 and Ghafoor 2015) of *Monoculus*, there is no mention of significant variation in the species.

During routine weed collecting we have recorded on several occasions in the Geraldton region plants with small flowers and small inflorescences (Figures 1 and 2). The inflorescence bracts of the small form are almost as long as the ray florets and not markedly recurved (Figure 1). The plants also differ in having short pure yellow ray florets, not dark red at the base (Figure 2). These can form pure populations, such as on granites at Bowles (west of Northampton, voucher GK/BK 1470, PERTH) or can co-occur such as at Coalseam Conservation Park with little sign of intergradation (voucher GK/BK 2374 &2375, PERTH).

Both forms are self- fertile and certainly the larger inflorescence form is readily visited by Honeybees (*Apis mellifera*).

DISCUSSION

As noted in the introduction there are 2 species of *Monoculus*, the other species, *M. hyoseroides* has much larger inflorescences with long orange-yellow ray florets and is obviously not the form we have recorded. However, Manning and Goldblatt (2012) have re-combined most of the genera previously segregated (*Chrysanthemoides*, *Monoculus*, *Oligocarpus* and *Tripteris*) back into a larger *Osteospermum*. This genus now comprises over 80 species of mainly African plants.

In the treatment by Manning and Goldblatt (2012) *Osteospermum monstrosum* is placed in the *Tripteris* annual group with two other small flowered species (*O. breviradiatum* and *O. microcarpum*) and not with *O. hyoseroides*. It is possible that the material we have noted is a form of *O. breviradiatum*, but we are currently unable to verify this, and given the previous generic placement by Nordenstam 2006 of only two species into *Monoculus* this seems unlikely.

In any case it appears that this weed either is much more variable than previously reported and perhaps contains several discrete forms that were separately introduced to Western Australia, or is a mixture of several taxa.

Figure 1. Side view of inflorescences from Coalseam Conservation Park.

Figure 2. Top view of inflorescences from Coalseam Conservation Park.

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CYNOGLOSSUM SUAVEOLENS (BORAGINACEAE) RECORDED FOR WESTERN AUSTRALIA

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In September 2006 during surveys of remnant bushland on the Dandaragan Plateau we established a series of quadrats in the Mogumber Townsite Reserve (reserve 8588). While undertaking general flora recording a population of 30 plants of an unusual herb was noted, photographed and collected (Voucher: Greg Keighery and Bronwen Keighery 850, PERTH, Photo 1). The plants were growing on the top of the riverine cliff along the Moore River (east branch) in deep brown loamy soils under Wandoo (*Eucalyptus wandoo*).

The plants were determined as *Cynoglossum suaveolens* R.Br. (Sweet Hounds Tongue, Photo 2). The genus *Cynoglossum* of the Boraginaceae contains c. 75 species in temperate regions of the world with two species, *Cynoglossum australe* R.Br. and *C. suaveolens* R, Br, recorded for Australia (Mabberley, 2002).

The highly variable annual to perennial *C. australe* (including plants attributed to *C. drummondii* Benth.) is found in all mainland states and Tasmania and extends into the arid. *Cynoglossum suaveolens* is normally listed from South Australia, Victoria, Tasmania, New South Wales and southern Queensland, in more temperate areas.

Currently the collection in Western Australia is listed as introduced on Florabase (Western Australian Herbarium 1998–). However, we consider that the material represents a native population for the following reasons.

1. A highly disjunct population of this species has been recorded from the Macdonnell Ranges in the Northern Territory at Ooraminna Rockhole in 1968 (Australian Virtual Herbarium), suggesting that the burred fruits allow for the species to be transported by waterfowl.

2. The site where the species was recorded is a relatively undisturbed and intact riverine site. This is a favoured habitat of the species in eastern Australia, but this habitat is now very rare in Western Australia. The site also contains populations of other rare species. Thus the species may have always been restricted in occurrence in WA and has escaped recording.

Photo 1. A view of around 50% of the *Cynoglossum suaveolens* population in Mogumber Townsite Reserve.

Photo 2. *Cynoglossum suaveolens* flowers.

3. Although the population is highly disjunct from the nearest occurrences on the Eyre Peninsula in Eastern Australia. Large disjunctions are not uncommon in widely dispersed temperate Australian species.

The Western Australian population should be compared to the Eastern Australian material to determine if it is genetically distinct as the only known Western population consists of 30 plants outside a conservation reserve alongside the road to the local refuse site. This population could easily be destroyed and probably disappear within a decade unless more populations are found or the plants are brought into cultivation and increased in the wild.

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RESULTS OF THE FIRST INTERTIDAL CITIZEN SCIENCE PROJECT IN WA: PORT HEDLAND COMMUNITY REEF SURVEY MARCH–APRIL 2014

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ABSTRACT

The Pilbara region is increasingly being recognised for hosting diverse and expansive coral reef communities. However in many nearshore locations, including Port Hedland, there is a lack of baseline data about the intertidal reef communities. In response to this gap in information, the community group "Care for Hedland" was awarded funding to establish a series of permanent monitoring sites that will enable temporal changes in the intertidal reef habitat to be documented. Here we report the results of the first baseline survey effort which was conducted in tandem with scientists from the Western Australian Museum in March–April 2014. Three permanent survey sites were established and two habitats were examined at each site – the mid- reef flat and outer reef flat. The surveys employed a number of established methods and gathered a variety of data at each site including site descriptions, rugosity measures, benthic cover estimates and diversity records. Spatial differences in the composition of intertidal communities were recorded both within and between sites. The highest level of hard coral cover was recorded at Cemetery Reef but the other sites also exhibited unique benthic features. This citizen science initiative represents the first community intertidal reef monitoring program in Western Australia and is an outstanding example of the potential of citizen science projects to contribute to science.

INTRODUCTION

Port Hedland, in Western Australia's Pilbara region, is an area well known for a significant amount of industrial development, for example the iron ore industry. However, less well known to the wider community is that diverse intertidal reef

ecosystems fringe the Pilbara coastline. Intertidal reefs are often harsh and dynamic environments. During low tide events the benthic organisms living in this zone must endure emersion, fluctuating temperatures, drying wind conditions, physical damage from waves and seasonal sediment and freshwater inundation.

In recognition of the importance of documenting intertidal reef diversity, abundance and health in the Pilbara, the community group Care For Hedland Environmental Association Incorporated (hereafter referred to as Care For Hedland) was awarded funding, and in-kind support from a number of agencies and groups (please see acknowledgments for a complete list), to establish monitoring sites. To instigate a program of ongoing community monitoring, three reef health surveys were conducted from March 31 to April 3, 2014, with the assistance of Western Australian Museum (WAM) scientists. This initiative represents the first citizen science intertidal reef monitoring program in Western Australia.

Background to Citizen Science

Citizen Science (CS) is research on just about any topic conducted in part or fully by amateur or non-professional scientists, usually under the guidance of professional scientists. It is an important and emerging field of research that complements and extends work conducted by professional scientists. Citizen Science is growing globally and gaining recognition by academics and in 2014 an 'Australian Citizen Science Association' was initiated to galvanise this growing movement nationally.

Reef Check is Australia's principal coral reef citizen science initiative. In 2013, Reef Check conducted subtidal reef monitoring at Ningaloo Reef, representing one of the first formal CS initiatives in Western Australia. The Pilbara study reported here followed Reef Check Australia's (RCA) subtidal monitoring program.

Background to the Pilbara region

The Pilbara region has extensive physical shaping forces including a large tidal range, strong currents and regular cyclones (BHP 2011). The tides along the Pilbara coasts are semidiurnal (Jernakoff *et al.* 1999) with a very large tidal range which at times exceeds 7 m. Strong currents also exist off the coast, especially during spring tides. The maximum flood tide rate is approximately 1.5 knots flowing in an easterly direction and ebbing in a north westerly direction (PHPA 2013). Port Hedland is situated on the coast of a subtropical dry region, exposed to the greatest frequency of cyclones in Australia, occurring between December and April. The frequency and intensity of these cyclones, causing high wind speeds, an influx of freshwater

and severe storm surges, can be highly damaging for marine habitats such as coral reefs, limiting their growth, and species diversity (BOM 2014). These forces acting on the loose sediments result in naturally high levels of suspended matter in the water column, often observed as high turbidity/poor water clarity. This effect is especially prevalent during tidal exchanges or storms, and additional disturbance of sediments by dredging activities only compound this effect.

Survey work in the area, along and offshore of the Pilbara coast has focused around fieldwork conducted by government, industry and university scientific teams. Extensive biodiversity surveys by the Western Australian Museum (WAM) occurred from 1998–2002 in the Dampier area (Jones *et al.* 2004), and the Montebello Islands and Barrow Island have received attention, as a result of their marine park status (e.g. DEC Management Plan 2007–2017). Recent benthic surveys have been conducted off Onslow in subtidal habitats as a result of the WAMSI dredging project node, with surveys of filter feeder communities by AIMS and WAM scientists. CSIRO scientists surveyed the diversity and abundance of marine vertebrate and invertebrate life in intermediate depths as part of a Net Conservation Benefits (NCB) funded program in the Pilbara area in 2013. Although the emphasis of the recent work has been nearshore, both of these projects have focussed on subtidal community diversity and abundance.

Background to the town of Port Hedland

Port Hedland is a highly developed town with major port infrastructure to service the iron ore industry based in the Pilbara. Regular and ongoing dredging is necessary to keep the port clear of sediments. Additional anthropogenic stressors include the discharge of brine into the ocean from desalination plants and the potential for invasive species introduction from ballast water (WAPC-PPIF 2012). Other nearshore stresses such as sediment and nutrient runoff, habitat loss, boating and anchoring impacts, waste disposal, overfishing, aquarium trade collection, climate change (e.g. as evidenced by the 1998 and 2006 bleaching events, Pearce *et al.* 2011) and extreme weather (2011 flood and 2013 cyclone and floods) all have the potential to negatively impact on reef habitats. There is also a high level of tourism, along with recreational activities, such as fishing, boating and diving, which if not monitored can negatively influence the unique biodiversity of the local marine habitats (Human 2010).

Currently no baseline data exists about the diversity, abundance and health of macrobenthos in the nearshore Port Hedland region coastal settings, where potential and actual impacts

from development are most pronounced. Hence, this survey, conducted as part of the Care For Hedland intertidal monitoring program, provides a unique opportunity for community engagement to assist in establishing a baseline for the Port Hedland marine macrobenthos, including sponges and corals.

MATERIALS AND METHODS

The survey preparation involved community participants, who were present for a review and discussion of factors routinely considered when preparing to survey, including an introduction to biodiversity and methods, survey methodology including site descriptions, collecting point intercept data along a transect, measuring rugosity, and biodiversity assessment at each of three sites. Although site selection is normally also part of survey preparation, the three sites were chosen prior to survey preparation by Care for Hedland. These sites were selected to provide a balance between scientific value and accessibility, and represent pristine (control) and more impacted (test) sites. The sites were: 1) Cemetery Reef (control site; healthy marine community close to town), 2) Cooke Point (Caravan Park) (impacted site; increased siltation has been observed over time) and 3) Finucane Island (future impacted site; planned development) (Figure 1; Table 1). All three sites have a long history of casual survey/photography through

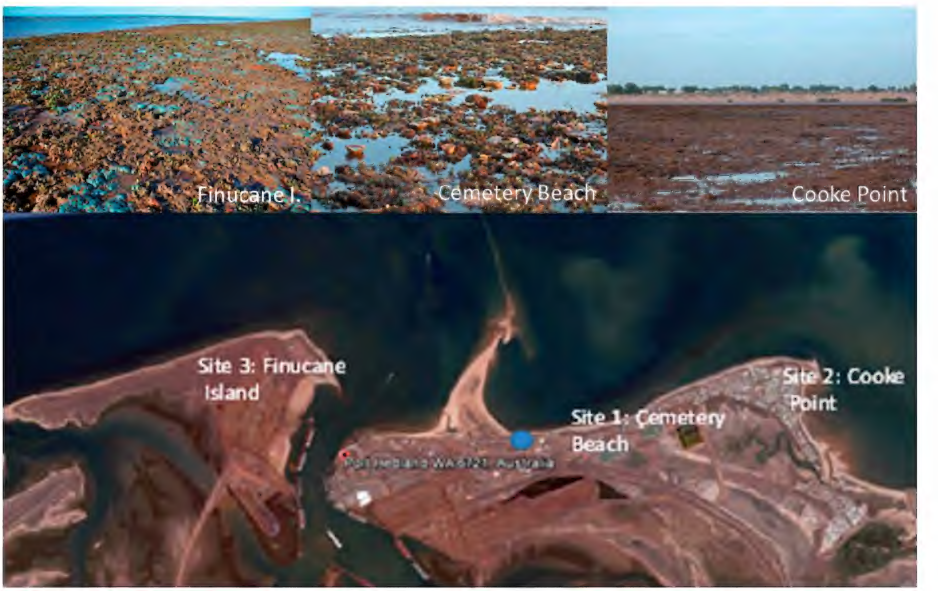

Figure 1. Map of Port Hedland indicating the 2014 community survey sites and habitats.

Table 1. Site descriptions.

Site 1 Cemetery Reef	Mid Reef Transect	Outer Reef Transect
Brief description	Intertidal reef with heavy silt, sand. Right of water tower on dead mini-bommie (end of transect line, between 2 creeks (front and back of line). 650 m from beach.	Intertidal reef with heavy silt, sand. Right of water tower. 750 m from beach. *Syrinx aruanus* present live & dead, largest was ~40 cm. No nudibranchs, no cephalopods. Sand covering surfaces common with mini waterfalls with coral & sponge garden. Slight slope 15 degree. At 5 metre gap, pool to left.
Date, Time, Water depth	April 1 2014. Time 6:00 am. 0–0.2m	April 1 2014. Time 6:30 am. 0–0.2m
Team leader	Shirley Slack Smith	Lisa Kirkendale
Data recorder	Pip Short	Lisa Kirkendale
Camera ID	Pip's Iphone	Doris Teufel
GPS	20 18 16, 118 36 38 ; 20 18 18, 118 36 34	20 18 14, 118 36 37, 20 18 15, 118 36 36
Compass bearing	bearing north ~60 and looking south 237	bearing north ~66 and looking south 241
Site 2 Cooke Point		
Brief description	Intertidal reef with heavy silt, sand due to proximity to adjacent tidal estuary (Pretty Pool). Mangroves on extensive sand flats. 1km from beach. No nudibranchs, no cephalopods. Sand covering surfaces common with mini waterfalls with coral & sponge garden. Transect positioned half in and half out of mini waterfall/creek, with first 0–20 in and second 25–45 out. Obvious slope 25 degrees.	Intertidal reef with heavy silt, sand due to proximity to adjacent tidal estuary (Pretty Pool). 1km from beach. No nudibranchs, no cephalopods. Sand covering surfaces common, with mini waterfalls with coral & sponge garden. Mangroves on extensive sand flats. Transect positioned half in and half out of mini waterfall/creek, with first 0–20 in and second 25–45 out. Obvious slope 25 degree.
Date, Time, Water depth	April 1 2014. Time 4:50 pm. 0–0.2m	April 1 2014. Time 4:50 pm. 0–0.2m
Team leader	Shirley Slack Smith	Lisa Kirkendale

Data recorder	Shirley Slack Smith	Lisa Kirkendale
Camera ID	Ruths' Work Iphone	Doris Teufel
GPS	Garmin: 20.30437,118.64349; 20.30466, 118.64384 LK Iphone: 20 18 16, 118 38 36; 20 18 17, 118 38 38	Garmin: 20. 30426, 118.64424 LK Iphone: 20 18 14, 118 38 38 20 18 14, 118 38 37;
Compass bearing	120 SE	125 SE
Site 3 Finucane Island		
Brief description	Intertidal exposed reef, coarse clean sand, more similar to Site 1 than Site 2. 450 m from beach. Cephalopod, long armed octopus! No nudibranchs. Sand covering surfaces common with mini waterfalls with coral & sponge garden and worm tube berms, also small pools quite common. Slope slight 10 degrees. Coral outside transect, at edge of pool. Sponges outside pool large. Pool and outside many small soft corals, pale yellow. In pool, small growth of corals. Outside transect pool, *Pinna* in hollow. Many black holothurians (*Holothuria atra*). Astreids with purple operculum. Corals (small colonies) Faviidae. *Turbinaria* small polyps not bleached.	Intertidal exposed reef, coarse clean sand, more similar to Site 1 than Site 2. 500 m from beach. Cephalopod, long armed octopus! No nudibranchs. Sand covering surfaces common with mini waterfalls with coral & sponge garden and very large and abundant worm tube berms, up to 1 m diameter x 0.5 m high, also small pools quite common. Slope slight 10 degrees, more like Site 1 than Site 2. Rocky headland framing the reef flat full of live oysters, chitons 2–3 spp), littorines, siphonariids, limpets. These were not obvious at other sites with sandy beach.
Date, Time, Water depth	April 2 2014. Time 5:30 am. 0–0.2m	April 2 2014. Time 5:58 am. 0–0.2m
Team leader	Shirley Slack Smith	Lisa Kirkendale
Data recorder	Ruth Allan	Lisa Kirkendale
Camera ID	Ruth Allan's Work Phone	Doris Teufel
GPS	20 17 36, 118 33 54	Garmin: 20.2926, 118.56474; 20. 29239, 118.56513 LK Iphone: 20 17 33, 118 33 53; 20 17 33, 118 33 54
Compass bearing	66 NE	60 NE

regular reef walks held annually since 2007, led by resident naturalist Doris Teufel. The time of year was selected to avoid the storm season and high summer temperatures.

Introduction to the Community Survey

On arrival, the group conducted a short intertidal survey at low tide on the evening of March 31. The site chosen was adjacent to that scheduled for the first community survey at Cemetery Reef on the following morning. The exercise was to find and collect macroinvertebrates and marine flora from the area so that Citizen Scientists could familiarise themselves with plants and animals on the reef. Material was largely studied in the field but some specimens were collected in a bucket and examined at the Masonic Lodge sorting area. The key features that can be used to separate easily confused major taxonomic groups (e.g. encrusting sponges from soft corals and compound ascidians or sea squirts) were examined. Team leaders highlighted the different forms of soft corals, hard corals and especially sponges. Further, survey methods, including the use of different types of gear, were discussed and members of the group were then introduced to techniques to be employed the following morning.

Survey

Two zones were surveyed at each site, the mid-reef flat and the outer reef flat. A detailed description including GPS coordinates was obtained for each survey station (Table 1).

Two 50 m transects were surveyed within each reef zone at each of the three sites. In order to ensure the same area is surveyed over time, permanent markers (10 cm lengths of rebar) were hammered into the reef at the beginning of two transect lines. A fibreglass transect tape was then draped securely along the surface of the reef flat between the permanent marker and a compass bearing that dictated the transect direction.

Along the transect line three main scientific activities were undertaken:

- Rugosity: A 10 m length of chain was draped over the reef adjacent to the transect tape to measure the topography of the reef. This procedure was repeated 3 times along each 50 m transect to obtain an average measure of rugosity. This is a standard method used by WAM on biodiversity surveys, but is not regularly utilized by RCA for subtidal surveys of coral reef habitats.
- Point Intercept Transect: Two 20m point-intercept transects (PIT) were conducted along each 50m transect tape (10 m gap in the middle). Hence four PITs were conducted within each reef zone at each site (Hill & Loder 2013). Along each transect the substrate, either abiotic, plant or animal,

Code	Substrate Category
Asc	Ascidian
BA	Brown Algae
BR	Bryzoan
GA	Green Algae
GF	Green Filamentous
HCB	Bleached Hard Coral
HCE	Encrusting Hard Coral
HCF	Foliose Hard Coral
HCM	Massive Hard Coral
LDC	Long Dead Coral
Ot	Other
RB	Rubble
RC	Rock
RCCA	Coralline Algae
RC + SD	Rock + Sand
RC + SI	Rock + Silt
RKC	Recently Killed Coral
RKCBA	Recently Killed Brown Algae
RKCGA	Recenty Killed Green Algae
RKCS	Recently Killed Soft Coral
SCL	Leathery Soft Coral
SCZ	Zoanthids
SD	Sand
SDRB	Sand + Rubble
SD + SI	Sand + Silt
SI	Silt
SPF	Foliose Sponge
SPB	Sponge Ball
SPBR	Branching Sponge
SPE	Encrusting Sponge
SPM	Massive Sponge
SPR	Rope Sponge
SPV	Volcano Sponge
TW	Tube Worm

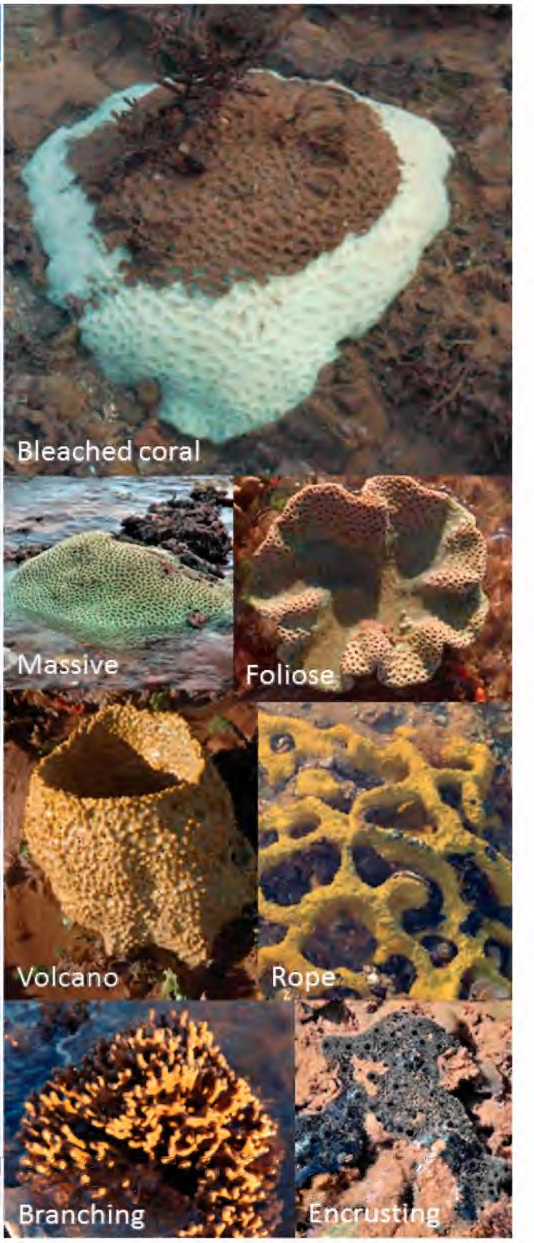

Figure 2. Substrate category codes and types for point-intercept transects.

and growth form (if living) occurring directly under the line, was recorded every 0.5 m. The benthic categories and codes used in the field followed RCA methods (Figure 2). A

health assessment of the living substrate (e.g. bleached or dead coral) was noted to assist in identifying and tracking potential impacts through time.

- Biodiversity: Benthic organisms that were commonly encountered were labeled, photographed and collected to enable species level identification by WAM experts.

Analysis

Percentage cover was calculated for PIT data collected along all transects (using Excel). A species list was generated for collected samples representing the common macrobenthic invertebrates encountered. Photographs of other organisms observed off transects (but not collected) are also presented.

RESULTS

The sites were within 10 km of each other. While they showed similarities in rugosity, which was uniformly low among sites (ranging from 0.92–1, Table 2), there were noticeable differences in benthic cover between reef sites and across zones (Figures 3 and 4).

Cemetery Reef had a substantially higher average cover of hard corals (10%) when compared to the other two locations, which

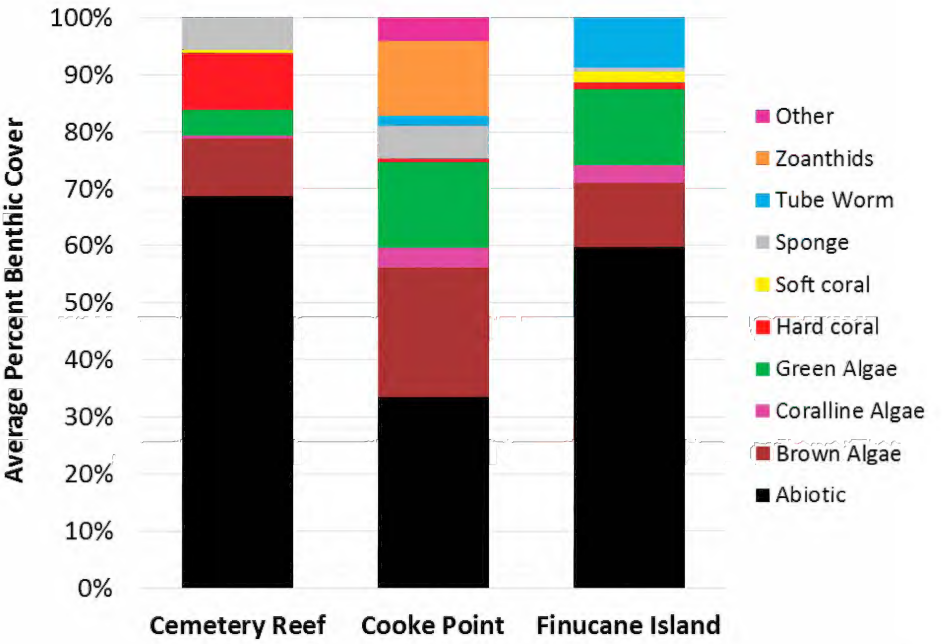

Figure 3. Average percent cover (across outer and inner reef habitats) of major benthic groups at the three 2014 survey sites.

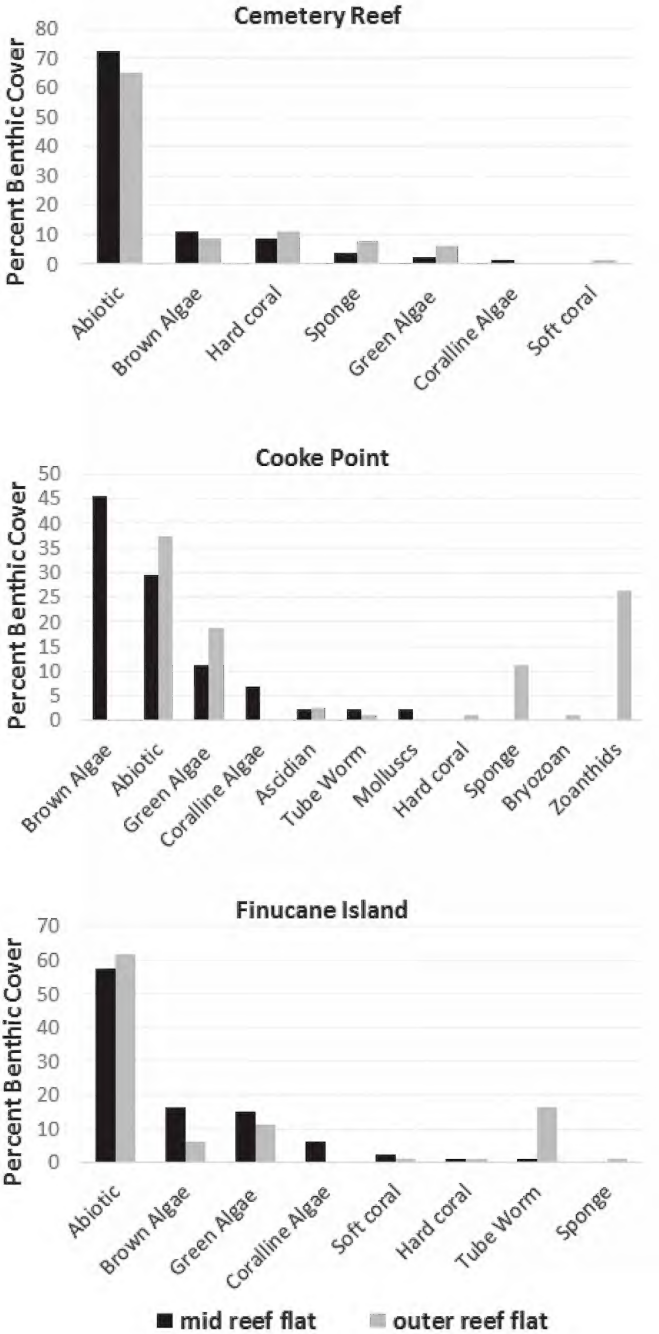

Figure 4. Percent benthic cover of main benthic groups at mid- and outer reef flat habitats at Cemetery Reef, Cooke Point and Finucane Island.

Table 2. Rugosity values.

	Cemetery Reef		Cooke Point		Finucane Island	
	Mid-reef zone	Outer reef zone	Mid-reef zone	Outer reef zone	Mid-reef zone	Outer reef zone
T1	0.87	0.96	0.96	0.995	1	1
T2	0.92	0.97	0.96	0.985	0.996	0.96
T3	0.96	0.97	0.99	0.968	0.995	1
T4	0.93	1	0.95	0.993	0.996	0.98
Average	0.92	0.975	0.965	0.98525	0.99675	0.985

had approximately 1% coral cover each (Figures 3 and 4). As well as hard coral cover, Cemetery Reef also had a very high level of abiotic cover (sand, rubble, silt), with sponges and brown and green algae commonly encountered. Cooke Point had the least amount of abiotic cover of all three sites, but often with distinct benthos characterizing mid-reef and outer reef zones. There was a high percentage cover of brown algae (45%), exclusively at the mid-reef site, a more even distribution of green algae (11% and 19% at mid- and outer reef zones, respectively) and a high percentage of zoanthids (26% cover) exclusively at the outer reef zone (Figure 4). No soft corals were encountered on transects at Cooke Point, however this group was observed off transect. A wider diversity of invertebrates including ascidians, molluscs and bryozoans were recorded at Cooke Point, relative to other sites (Figure 4). Similar to Cemetery Reef, Finucane Island was dominated by abiotic substrate at both mid- and outer reef flat zones (Figure 4). A large biomass of tubeworms (17% cover at the outer reef zone, Figure 4) was notable. Sponges were less common at Finucane Island com-

Figure 5. Common intertidal benthic organisms recorded at Port Hedland. **A)** Green algae – *Halimeda* spp. observed at all sites; **B)** Green algae *Neomeris* sp. observed at most sites; **C)** Brown algae *Sargassum* spp. observed at all sites; **D)** Purple Sponge *Oceanapia* sp. 6, WAM Z68729_S13 observed at Cemetery Reef; **E)** Green sponge from Cooke Point; **F)** Orange sponge *Reniochalina stalagmitis*, WAMZ68702_S6 observed at Finucane Island; **G)** Small barrel sponge, *Pseudoceratina* cf *verrucosa*, WAM Z68726_S23a observed at Finucane Island; **H)** Vase sponge, *Ectyoplasia frondosa* WAM Z68728_S3 observed at Finucane Island; **I)** Bleached neptheid soft coral from Cooke Point; **J)** Bleached soft coral colony of *Sinularia* sp. 1 from Cemetery Reef; **K)** Healthy, unbleached *Sarcophyton* soft coral from Cooke Point with polyps extended for feeding; **L)** Hard coral *Duncanopsammia axifuga* observed at Finucane Island; **M)** Vase coral *Turbinaria mesenterina* observed at all sites; **N)** *Euphyllia ancora* observed at Cemetery Reef; **O)** *Moseleya latistellata* observed at Cemetery Reef.

pared to the other two sites, but there was a high level of green and brown algal average cover (13 and 11%, respectively Figure 3) found here.

A great diversity of benthic organisms was encountered both on and off transects (Figure 5; Table 3) during the survey. Twenty one species (or taxonomic units) were identified from the material collected (Table 3).

DISCUSSION

As a result of this study major common features were observed with conspicuous macroalgal or seaweed, hard coral and soft coral genera identified that were shared among the sites. Zonation was evident between the inner and outer reef areas, with macroinvertebrate and macroalgal biodiversity increasing to the outer reef edge. Dominance of some groups was apparent within each site and distinctive in its faunal composition. For example, Site 2 at Cooke Point had a dense cover of zoanthids on the outer reef flat. Site 3 at Finucane Island had outer reef worm berms or towers that could be seen from the shore and were not observed at this density at any of the other sites. These worms belong to the genus *Idanthyrsus* sp. in the family Sabellariidae and may be one of the eight new species named and described recently (Hutchings *et al.* 2012).

The reef topography at Site 1 (Cemetery Reef) was, on average, more rugose than Site 2 (Cooke Point), which was more rugose than Site 3 (Finucane Island). This latter result is surprising given the observation of worm towers at that site. The outer reef zones were less rugose than the mid-reef zones at Sites 1 and 2, but the mid-reef zone was more rugose at Site 3. The overall low rugosity values may reflect the effects of cyclone damage in January 2014, which might have toppled corals and emergent sponges in these areas. Sand and sediment was apparent at all sites. The occurrence of these substrates covering reefal surfaces is of concern, as these substrates can fill depressions on the reef. Depressions, which often become small pools with cryptic areas, offer reef complexity that serve as important refuges on otherwise flat and exposed reef platforms. Alternately, soft sediments could provide new habitat opportunities for burrowing taxa, such as sand dwelling molluscs (e.g. many bivalves but also gastropods), as well as specialist holothurians. Although not the focus of this survey, newly settled larvae, as well as motile organisms, often utilise such features. The great diversity of motile invertebrates observed and photographed over the years at these sites by one of us (D. Teufel) drives home the importance of these refugia.

Cemetery Reef was dominated by abiotic substrates. In contrast, Cooke Point had a lower cover of abiotic substrate and almost half

of the mid-reef zone was covered by the brown algae *Sargassum*, while approximately a quarter (26.25%) of the outer reef zone was covered by zoanthids. Finucane Island showed more similarities with Cemetery Reef than Cooke Point being dominated by abiotic substrata and having a high cover of green algae (including species of the genera *Neomeris, Udotea, Halimeda* and *Caulerpa),* however Finucane Island was uniquely characterised by the presence of tube worms.

Sponges formed the main macrobenthic group targeted for collection and for identification at WAM due to their dominance (especially in the outer reef flat zones across sites) and the lack of field characters for easy identification by non-specialists, (Figures 3, 5; Table 3). All sponge species identified had been found in the Pilbara previously and were known to occur on intertidal reef flat habitats typical of the region. Representatives from the family Tethyidae were present at all three sites, as were two species of the genus *Hyatella* in the Family Spongiidae (Table 3). Sponge diversity differed among sites, with almost double the number of species reported from Site 3 (9 species) compared to Sites 1 and 2 (5 species). However, this result is at least partly an artifact of sampling effort, with more time spent collecting samples later in the survey when the field methods were routine. A similar trend was evident between zones, with more sponge samples collected from outer reef sites than from mid-reef sites. There were also differences in diversity and abundance in the sponge fauna observed in the outer zone which may be related to more constant conditions at outer reef sites, including less exposure to air (and disturbance by storms) during extreme low tides. In addition a new sponge barnacle, *Euacasta* sp. nov., was found during the survey in the sponge host *Ectyoplasia frondosa* (WAM Z68728) and this new species will be formally described in the future.

Four hard coral species were identified and collected from Sites 1 and 3, however additional species were observed off transect that were not collected. The vase coral *Turbinara mesenterina* was most conspicuous at Site 1, with recruits in the mid-reef zone, and the largest colonies observed in the outer reef zone. This species was found at all sites, but was unfortunately found most commonly as 'topples' (dead on the reef). Such deaths were probably a result of cyclone damage earlier in the year. Three soft coral species were identified and collected from Cemetery Reef and Finucane Island. No soft corals were collected from Cooke Point (Table 3). A large colony of *Sinularia* sp. 1, subsampled from the mid-reef zone at Cemetery Reef, was entirely bleached (Figure 5). Susceptibility to bleaching may be related to

Table 3. Benthic organisms collected on the 2014 fieldtrip and registered into the WA Museum Aquatic Zoology collection.

Phylum	Class	Order	Family
Porifera	Demospongiae	Dictyoceratida	Spongiidae
Porifera	Demospongiae	Dictyoceratida	Spongiidae
Porifera	Demospongiae	Dictyoceratida	Spongiidae
Porifera	Demospongiae	Dictyoceratida	pongiidae
Porifera	Demospongiae	Halichondrida	Axinellidae
Porifera	Demospongiae	Hadromerida	Tethyidae
Porifera	Demospongiae	Hadromerida	Tethyidae
Porifera	Demospongiae	Hadromerida	Tethyidae
Porifera	Demospongiae	Hadromerida	Tethyidae
Porifera	Demospongiae	Poecilosclerida	Iotrochotidae
Porifera	Demospongiae	Verongida	Pseudoceratinidae
Porifera	Demospongiae	Verongida	Pseudoceratinidae
Porifera	Demospongiae	Hadromerida	Clionaidae
Porifera	Demospongiae	Poecilosclerida	Raspailiidae
Porifera	Demospongiae	Haplosclerida	Phloeodictyidae
Porifera	Demospongiae	Dictyoceratida	Spongiidae
Porifera	Demospongiae	Halichondrida	Halichondriidae
Chordata	Ascidiacea		
Chordata	Ascidiacea		
Cnidaria	Anthozoa	Scleractinia	Dendrophyllidae
Cnidaria	Anthozoa	Scleractinia	Dendrophyllidae
Cnidaria	Anthozoa	Scleractinia	Poritidae
Cnidaria	Anthozoa	Scleractinia	Merulinidae
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae

differences in taxonomic resilience, but this trend could also be explained by more constant conditions, including less exposure to heat (and storms) during extreme low tides on the outer reef. Anecdotal reports suggested many of the soft corals recovered from bleaching with the return of cooler winter sea temperatures (Doris Teufel 2014 pers comm).

Genus	species	WAM Reg. No.	Station Number	Determined By
Hyattella	sp. 1	68706	S1T1S2-S10	Fromont, J.
Hyattella	sp. 1	68707	S2T2S4-S18	Fromont, J.
Hyattella	cf. *intestinalis*	68708	S1T1S3-S11	Fromont, J.
Hyattella	cf. *intestinalis*	68709	S3T2S5-S20	Fromont, J.
Reniochalina	*stalagmitis*	68702	S3T2O4-S6	Fromont, J.
Anthotethya	*fromontae*	68720	S3T2S3-S22	Fromont, J.
Tethya	cf. *robusta*	68721	S1T1SC1-S1	Fromont, J.
Tethya	cf. *robusta*	68722	S2T2S5-S15	Fromont, J.
Tethya	cf. *robusta*	68723	S2T2S3-S17	Fromont, J.
Iotrochota	sp. KMB1	68724	S2T2S1-S14	Fromont, J.
Pseudoceratina	cf. *verrucosa*	68725	S3T2S1-S2	Fromont, J.
Pseudoceratina	cf. *verrucosa*	68726	S3T2S4-S23	Fromont, J.
Spheciospongia	sp. PB1	68727	S2T2S2-S16	Fromont, J.
Ectyoplasia	*frondosa*	68728	S3T2S2-S3	Fromont, J.
Oceanapia	sp. 6	68729	S4-S13	Fromont, J.
Carteriospongia	sp. 1	68730	S2T2O3-S19	Fromont, J.
Ciocalypta	*tyleri*	68731	S3T2O5-S7	Fromont, J.
		68732	S3T2O2-S4	Fromont, J.
		68733	S3T2SC2-S21	Fromont, J.
Duncanopsammia	*axifuga*		S3T1SC4	Richards, Z.
Turbinaria	*mesenterina*		S1T1HC3	Richards, Z.
Goniopora	*somaliensis*		S3T1HC1	Richards, Z.
Coelastrea	*aspera*		S1T1HC4	Richards, Z.
Sinularia	sp. 1		S1T1SC2	Bryce, M.
Lobophytum	sp. 1		S3T2SC1	Bryce, M.
Lobophytum	cf. *sarcophytoides*		S1T2SC1	Bryce, M.

A high level of silt and sand was present on all reefs as indicated by the percentage-cover data. Silt and sand can smother reefs and inhibit the recruitment of corals and other sessile invertebrates. Ongoing reef checks to monitor the mobilization of this sediment could indicate such movement and also show whether a low level of rugosity is a result of natural depressions being filled with sand.

CONCLUSIONS

The coastal Port Hedland filter feeding reefs and marine gardens are special. They contain a rich biodiversity and abundance of sponges, hard corals, soft corals, macro-algae and other taxa. A variety of growth forms for each of the macrobenthos can provide shelter at high tide for a number of motile marine vertebrates and invertebrates. The reef can be considered to be naturally resilient because of its long history of regular disturbances including cyclones, large tidal regimes, and natural sediment loadings. However, because of the addition of multiple stressors, particularly anthropogenic pressures, most notably those connected with industrial development in the region, these reefs may reach tipping points in the future. The most viable strategy to track natural and anthropogenic effects on reef communities in these remote locations is employing regular long term monitoring by active community members (Citizen Science). Since the first baseline survey reported here, two additional surveys have been conducted with new sampling sites added. Such developments attest to the strength of the community's engagement and its 'Care For Hedland' approach.

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A SOUTHERN RANGE EXTENSION FOR THE BLACK-HEADED PYTHON *ASPIDITES MELANOCEPHALUS* IN WESTERN AUSTRALIA

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INTRODUCTION

The endemic Australian python genus *Aspidites* is represented by only two species, the Black-headed Python, *A. melanocephalus* (Krefft 1864) and Woma Python, *A. ramsayi* (Macleay 1882) (Cogger *et al.* 1983; Smith 1981). The two *Aspidites* species largely differ from other Australian pythons in that they possess narrow heads, often not much wider than the neck and the lack of heat-sensitive pits on labial scales (Barker and Barker 1994; Storr *et al.* 2002). The Black-headed Python is a large species that can attain lengths up to 3 m, distinguishable from the Woma Python by its prominent black head and alternating pale creamy-white to yellow and black banding along the length of body and tail (Smith 1981; Storr *et al.* 2002). It is often mistaken for a venomous species and killed by those not familiar with the species due to broad morphological similarities with some venomous species particularly brown snakes (genus *Pseudonaja*) including the narrow head and lack of heat-sensing pits on labial scales (Smith 1981; Storr *et al.* 2002). The species can also imitate the defensive behaviour of some venomous species when threatened or cornered, in particular taking up an aggressive stance including raising of the head and forebody, hissing and repeated striking (Barker and Barker 1994; Bush and Maryan 2011). The Black-headed Python is an oviparous species with a variable diet consisting of predominantly reptiles, which occasionally includes highly venomous snakes (*Pseudechis* and *Pseudonaja* spp.) and large goanna species (*Varanus* spp.) (Barker and Barker 1994; Bush and Maryan 2011; Cogger 2014).

The Black-headed Python is found in a range of habitats across northern Australia from seasonally dry forests and woodlands to arid grassland and shrubland habitats associated with a variety of substrates and geology from sandplains through to rocky hills (Bush and Maryan

2011; Cogger 2014). Its distribution extends across northern Australia from Queensland through the Northern Territory and into Western Australia with sparse records of the species in the central arid interior of Australia. In Western Australia its distribution extends throughout the Kimberley and south into the Pilbara region with records as far southwest as Cape Range and southeast to Jiggalong in central Western Australia (Figure 1). Storr, Smith and Johnstone (2002) provided comment of unconfirmed records of the species further south of its range from Cobra Homestead and 21 km west of Mt Vernon; however, the records could not be confirmed due to limited or lack of documentation and/or specimens.

Here we report on three observations of the Black-headed Python south of its current known distribution in Western Australia from Mt Augustus National Park, Mt Sandiman Station and Cobra Gifford Creek Road between Mangaroon and Cobra Stations northwest of Mt Augustus National Park.

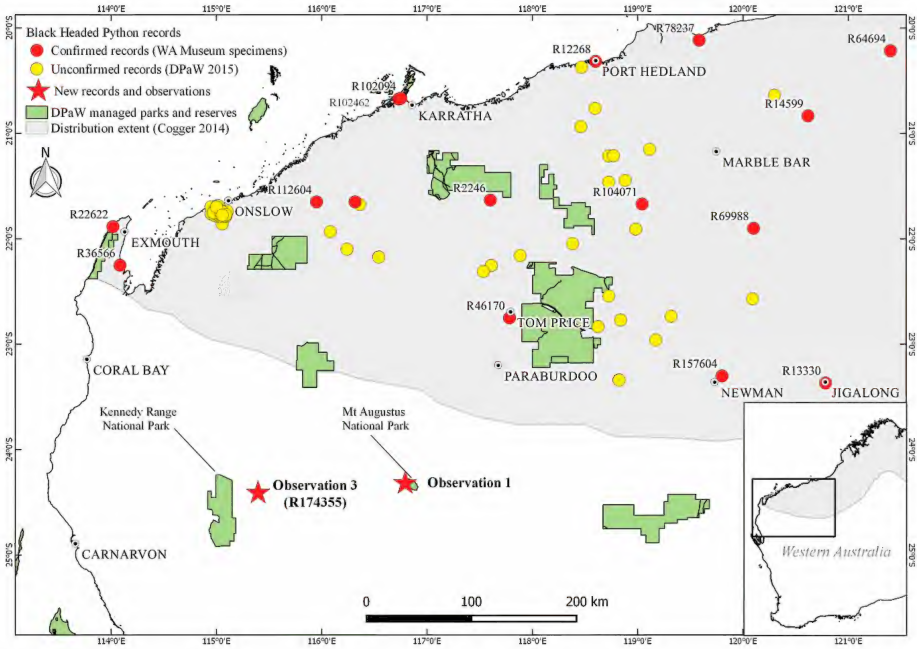

Figure 1. Distribution and records of the Black-headed Python (*Aspidites melanocephalus*) in Western Australia. Confirmed records are based on specimens held in the WA Museum collection where identification can be verified (WAM registration numbers presented). Unconfirmed records are based on NatureMap records which cannot be verified. Due to the lack of precise locality data, observation 2 is not presented.

OBSERVATIONS

Observation 1

On 9 May 2012 one of us (GH) observed and photographed a live Black-headed Python approximately 2.1 m in length on the Loop Road, Mt Augustus National Park (24°19'12.82"S, 116°47'34.47"E) located approximately 158 km south-west of Paraburdoo, 355 km north north-east of Carnarvon (Figure 1; Figure 2). The specimen was observed at approximately 0900 hr basking on the road near a small unnamed drainage line with seasonal pools of water present surrounded by *Acacia* shrubland dominated sandplains. The specimen was removed from the road and photographed prior to its release off the road amongst nearby vegetation.

Observation 2

On 30 August 2013 a Department of Parks and Wildlife Volunteer Camp Ground Host for Mt Augustus National Park observed and photographed a Black-headed Python northwest of Mt Augustus National Park on the Cobra Gifford Creek Road between Mangaroon and Cobra Stations, approximately 250 km north-east of Carnarvon (Figure 3), precise GPS coordinates were not collected at the time of observation. The individual was first observed crossing the road at approximately 1515 hr before retreating to a wood pile on the side of the road. Habitat adjacent to the road was dominated by Mulga woodlands on flat to low undulating plains.

Figure 2. Black-headed Python (*Aspidites melanocephalus*) recorded from Mt Augustus National Park (Observation 1). Photo: Gary Hearle.

Figure 3. Black-headed Python (*Aspidites melanocephalus*) recorded from Cobra Gifford Creek Road northwest of Mt Augustus National Park (Observation 2). Photo: Janine Guenther.

Observation 3

On 6 September 2015 a dead snake was collected from around the Mt Sandiman Station homestead (24°24'41.36"S, 115°23'44"E) located approximately 200 km north north-east of Carnarvon, Western Australia (Figure 1; Figure 4). The snake was collected from near the station home-

Figure 4. Black-headed Python (*Aspidites melanocephalus*) specimen recorded from Mt Sandiman homestead (R174355) (Observation 3). Photo: Ryan Ellis.

stead where surrounding habitat consists of rocky hills surrounded by plains supporting a mosaic of mulga vegetation. The specimen measured approximately 1.7 m in length and could not initially be identified by the collector who had not previously observed the species. The specimen was subsequently given to Department of Parks and Wildlife staff at the Carnarvon regional office who confirmed its identity as a Black-headed Python. Review of the record in relation to the species current range confirmed that it was outside the current known range of the species and the specimen was deposited with the Western Australian Museum where it is now maintained in the herpetology collection, registration R174355.

DISCUSSION

The three records of the Black-headed Python presented here south of the previously presumed southernmost known extent of its distribution indicate the southern extent of the species distribution is not well known. The record of the Black-headed Python from Mt Augustus National Park and Mt Sandiman extends the known distribution south by approximately 106 km and 116 km (Figure 1). Prior to this record the former most southerly confirmed record of the species was from Jiggalong (R13330; 23°22'00"S, 120°47'00"E) collected 15 March 1959. The current most southern record, Mt Sandiman, is located approximately 599.7 km west of the Jiggalong specimen. The nearest unconfirmed record of the species is a NatureMap record located approximately 274.5 km north north-east of Mt Sandiman (DPAW 2015); however, the validity of this and other records in the vicinity are unconfirmed.

In addition to the three observations presented here, a number of additional potential records of the species in the region have been identified, though many remain unconfirmed due to the lack of supporting evidence to confirm species identification such as photographs, specimen or other evidence and/or precise location information.

The three observations presented here support the previously unconfirmed southern records of the species discussed by Storr *et al.* (2002). The lack of confirmed records of the species within the vicinity of these records or the area between these records and previous confirmed records in the south of the species range is likely to be attributed to the reduced activity and lesser survey effort within the region in comparison to other regions where more records have occurred such as the Pilbara. More numerous records of the species in parts of the Pilbara region are likely to be attributed to the large scale Pilbara biodiversity survey

undertaken by the Department of Environment and Conservation (now Department of Parks and Wildlife) in addition to extensive fauna surveys undertaken for mineral exploration and mining activities. Further surveys and collection of observational records are likely to refine the extent of distribution of the species within Western Australia, particularly in the south of the species current known distribution.

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RANGE EXTENSION AND MICRO-HABITAT USE OF BUFF-SNOUTED BLINDSNAKE *(ANILIOS MARGARETAE)* WITH NOTES ON ITS CONSERVATION STATUS

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INTRODUCTION

Like most Anilios, *A. margaretae* is a poorly known species and until recently was only known from a single holotype (R15710) (Storr 1981) which was collected in 1962 by Harry Butler from the Lake Throssell (27°25'S, 124°18'E) area in central Western Australia (Storr *et al.* 2002). The type locality is typical of the Great Victoria Desert consisting of red sand dunes and plains of *Triodia* spp. with mixed low shrubs. The actual lake is normally a dry claypan and surrounded by some grasslands and has chenopod habitat (Storr *et al.* 2002). This habitat is represented as Beard 676 "Succulent steppe; samphire" and community 84 "Hummock grasslands, open low trees and mallee steppe; marble gum (*Eucalyptus gongylocarpa*) and mallee (*Eucalyptus youngiana*) over hard spinifex on sandplain (Beard 1974).

The specimen was approximately 300 mm long, very slender with an angular snout. The nasal cleft proceeds from the second labial and has 18 mid body scales (Storr *et al.* 2002). The species is much like *A. bituberculatus*, however is smaller, more elongate and not as strongly tri-lobed in the snout (Storr *et al.* 2002).

Taxonomy of blindsnakes in this paper follows Hedges *et al.* (2014) and conforms with the current version of the Checklist of the Terrestrial Vertebrate Fauna of Western Australia (Anon. 2014).

HISTORICAL RECORD

Since the holotype only one additional specimen had been recorded until our observation. This additional specimen was pit trapped in 2008 from a survey undertaken at Neale Junction Nature Reserve approximately 205 km south east of the holotype location (Brennan *et al.* 2009) (28°41'19S, 125°50'59E (R163269)). This specimen's capture location falls within either vegetation community 239 "Marble gum (*Eucalyptus gongylocarpa*) and mallee (*E. youngiana*) over *Triodia basedowii* between dunes" or 1239 "Marble gum (*E. gongylocarpa*) and mallee (*E. youngiana*) over *T. basedowii* on sandplain" (Beard 1974).

Plate 1. Image of *A. margaretae*

Plate 2. Head image of *A. margaretae*

THIS OBSERVATION

On 21 April 2011 an *A. margaretae* was unearthed at a location (29°10.326'S, 125°46.031'E) along the Connie Sue Highway, approximately 40 km south of the specimen recorded in Neale Junction Nature Reserve. During digging in pit lines a section of a termitaria chamber was bisected revealing the *A. margaretae*. The chamber was approximately 5–7 mm in diameter and lined with castings. Also within the chamber other than termites were hundreds of small pieces of cut\harvested grass and triodia in storage. The depth of the chamber was approximately 300 mm from the surface. The specimen was long and slender being 201 mm long with a snout-vent length of 197 mm and a body width of 2.5 mm. The body colouration was pink merging into a slightly lighter underbelly, prominent black eye patches and slightly tri-lobed pale orange snout (Plates 1 and 2). The specimen was photographed and released at the point of capture.

Plate 3. Habitat 40km South of Neal Junction Nature Reserve

The capture site was tall mallee shrubland with mid-storey of mixed low open shrubs over open hummock grassland on sandplain (Plate 3). The habitat community of the area is Beard 85 "Marble gum (*E. gongylocarpa*), mallee, *T. basedowii* on sandplain" (Beard 1974).

The area had been long unburnt and had good build-up of leaf litter under mallee. The soil was red sand with scattered low termitaria present.

CONSERVATION LISTING

Currently the species is listed as Priority 2 under Department of Parks and Wildlife Priority Fauna List (DPaW 2015). The listing refers to "Species that are known from one or a few collections or sight records (generally less than five), some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, vacant Crown land, water reserves, etc. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes."

CONCLUSION

This record of *A. margaretae* from approximately 40 km south of Neale Junction Nature Reserve represents a range extension for the species. All three individuals

(holotype and two subsequent individuals) have been found across an area spanning approximately 220 km from Lake Throssell to south of Neale Junction Nature Reserve. The vegetation communities at the capture locations are Beard 239, 1239, 676, 84 and 85 (Beard 1974). These vegetation communities are within the IBRA bioregion "Great Victoria Desert 2" and within subregion "central" and comprise the dominant vegetation communities in that region. This area is vast and covers approximately 68,203,314 ha within the mentioned vegetation communities above.

Although only three specimens have been recorded so far the species has been captured over a large area comprising numerous vegetation communities over a broad bioregion. The lack of captured individuals would seem to reflect the lack of surveys in the region and the highly cryptic nature of *Anilios* spp. in general, rather than specific threatening processes. *A. margaretae* does not appear to be under any threat and is likely to be just a small blindsnake in a big desert. A revision of its conservation status can only be made once more specimens are located.

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